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ADVANCED EXTRAVEHICULAR ACTIVITY
SYSTEMS REQUIREMENTS DEFINITION STUDY

NAS9-17779

EXTRAVEHICULAR ACTIVITY AT GEOSYNCHRONOUS EARTH ORBIT

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ADVANCED EXTRAVEHICULAR ACTIVITY
SYSTEM REQUIREMENTS DEFINITION STUDY
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PHASE I
EXTRAVEHICULAR ACTIVITY AT
GEOSYNCHRONOUS EARTH ORBIT

FINAL TECHNICAL REPORT

22 JANUARY 1988

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EVA at GEO

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FOREWORD

This final technical report summarizes work accomplished in an eight-month study to define the unique requirements necessary to support and accomplish extravehicular activity at Geosynchronous Earth Orbit.

The study was carried out under the technical direction of Terry O. Tri and Susan Schentrup of Lyndon B. Johnson Space Center, by Nicholas Shields, Jr. of Essex Corporation, Arthur E. Schulze and Stephen Altobelli of Lovelace Medical Foundation, and Gerald P. Carr and William Pogue of CAMUS, Incorporated.

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CONTRACT OVERVIEW

The basic contract to define the system requirements to support Advanced Extravehicular Activity has three phases, each covering eight months as follows:

- Phase I - EVA in Geosynchronous Earth Orbit (May 1987 - January 1988)
- Phase II - EVA in Lunar Base Operations (January 1988 - September 1988)
- Phase III - EVA in Manned Mars Surface Exploration (September 1988 - May 1989)

The three key areas to be addressed in each phase are:

- Environmental/Biomedical Requirements - Lovelace Medical Foundation
- Crew and Mission Requirements - CAMUS, Incorporated
- Man/Machine Interface and Hardware Requirements - Essex Corporation

The structure of the technical tasks closely follows the structure of the Advanced EVA studies for Space Station completed in 1986.

APPROACH TO DERIVING REQUIREMENTS TO SUPPORT EVA AT GEO

- Search of current literature which defines the GEO environment, the role of humans at GEO, and the support systems required to perform operations at GEO.
- Interviews with, and questionnaires from, NASA and industry technical experts involved in advanced mission planning and advanced EVA requirements analyses.
- Review of past EVA missions, interviews with crew-members, and review of proposed EVA missions.
- Review and incorporation of current man-systems standards and EVA design guidelines.
- Review of video and film records of EVA missions and EVA training sessions.
- Review of EVA equipment and tool catalogues.
- Concept formulation of equipment and approaches to support EVA-related activities at GEO.

ACRONYMS AND ABBREVIATIONS

ACRONYM/ABBREVIATION	DEFINITION
+ Gx	Forward acceleration
+ Gy	Right yaw acceleration
+ Gz	Upward acceleration
+ Rx	Left roll velocity
+ Ry	Forward pitch down velocity
+ Rz	Right yaw velocity
- Gx	Backward acceleration
- Gy	Left yaw acceleration
- Gz	Downward acceleration
- Rx	Right roll velocity
- Ry	Backward pitch up velocity
- Rz	Left yaw velocity
1/3 OB	One-third octave band
ACGIH	American Conference of Governmental Industrial Hygienists
ADS	Altitude decompression sickness
ADVEVA	Advanced extravehicular activity
AGC	Automatic gain control
AI	Articulation index
AIAA	American Institute of Aeronautics and Astronautics
Al	Aluminum
AL(Event)	Anomalistically large event
ALARA	As low as reasonably achievable
ANSI	American National Standards Institute
Ar	Argon
A/R	Automation/robotics
ARAMIS	Automation, Robotics and Machine Intelligence System
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers

ACRONYM/ABBREVIATION	DEFINITION
ASME	American Society of Mechanical Engineers
ATA	Atmospheres, absolute
ATM	Apollo Telescope Mount
ax	x-axis acceleration
ay	y-axis acceleration
az	z-axis acceleration
BFO	Blood forming organs
BHS	Body heat storage
BIB	Built-in breathing
BITE	Built-in test equipment
BTPS	Body temperature and pressure saturated with water
Btu	British thermal unit
C	Celsius
cal	Calorie
cc	Cubic centimeters
CCTV	Closed circuit television
CD	Compact disk
CERV	Crew emergency rescue vehicle
CFU	Colony forming units
cm	Centimeter, (also) Center of mass
CNS	Central nervous system
CO_2	Carbon dioxide
Com, Comm	Commications
CRS	Cosmic ray source
CRT	Cathode ray tube
CUM	Cumulative
CWS	Caution and warning system
D	Absorbed dose
DACT	Disposable absorbent containment trunk
dB	Decibels
DB	Dry bulb temperature
DCS	Decompression sickness

ACRONYM/ABBREVIATION	DEFINITION
DE	Dose equivalent
DEMUX	Demultiplexer
DIA, dia	Diameter
DIPS	Dynamic isotope power system
DOD	Department of Defense
DOF	Degrees of freedom
e	Electron
E	Energy
ECG	Electrocardiogram
ECLSS	Environmental control and life support system
ED10	10% of population showing physiological response to ionizing radiation
EDK	Electric dynamic katathermometer
EEG	Electroencephalograph
EEU	Extravehicular Excursion Unit
EIRP	Effective incident radiated power
EITP	Extravehicular inflight training package
EKG	Electrocardiogram
EL	Exposure limits
ELF	Extremely low frequency
EM	Electromagnetic
EMI	Electromagnetic interference
EOMV	Enhanced orbital maneuvering vehicle
EMU	Extravehicular mobility unit
E/R	Extender/retractor
ESSA	Environmental Sciences Services Administration
ET	Effective temperature
eV	Electron volts
EV	Extravehicular
EVA	Extravehicular activity
F	Fahrenheit
FDA	Food and Drug Administration

ACRONYM/ABBREVIATION	DEFINITION
FDP	Fatigue decreased proficiency, (also) Flight Planning Document
Fe	Iron
FMEA	Failure modes and effects analysis
FSS	Flight support system
FSW	Feet of seawater (33 FSW = 1 Atmosphere)
Ft	Feet
G	Gravitational acceleration
GC/MS	Gas chromatograph/mass spectrometer
GCR	Galactic cosmic radiation
GEO	Geosynchronous Earth orbit
GeV	Giga electron volt (billion)
GFK	Generic fabrication kit
GIAG	Government Industry Advisory Group
GT	Global temperature
g	gravity
gx	Vibrational acceleration in the direction of the x-axis
gy	Vibrational acceleration in the direction of the y-axis
Gy	Gray (radiation dosage unit of measure)
gz	Vibrational acceleration in the direction of the z-axis
H	Hydrogen
He	Helium
Hg	Mercury
HMD	Helmet-mounted display
HPA	Holding and positioning aid
hr	Hour
HUD	Heads-up display
HUT	Hard upper torso
Hx	Diatomic hydrogen

ACRONYM/ABBREVIATION	DEFINITION
Hz	Hertz (cycles per second)
HZE	Ultra heavy nuclear particles
Icl	Insulation value of clothing
IDB	In-suit drink bag
IEEE	International Electronics and Electrical Engineers
in	Inch
INIRC	International Non-ionizing Radiation Committee
IR	Infrared, (also) Ionizing radiation
IRPA	International Radiation Protection Association
ISO	International Standards Organization
ISSS	International Symbol/Signal System
IV	Intravenous
IVA	Intravehicular Activity
JSC	Johnson Space Center
K	Kelvin
KA(Band)	26.5 to 40.0 Gigahertz (one billion Hertz)
KB	Kilobit
kbps	Kilobits per second
kcal	Kilocalories (1000 calories)
KeV	kilo electron volt (thousand)
kg	Kilogram
km	Kilometer
Kmh	kilometer per hour
kPa	Kilo pascal
Kr	Krypton
KU(Band)	12.4 to 18.0 Gigahertz
kw	Kilowatts
KSC	Kennedy Space Center
Laser	Light amplification by stimulated emission of radiation
Lb	Pound
LBNP	Lower body negative pressure

ACRONYM/ABBREVIATION	DEFINITION
LCG	Liquid Cooled Garment
LCVG	Liquid cooling ventilation garment
LD50	Lethal dose of ionizing radiation for 50% of the population
LED	Light emitting diode
LEO	Low Earth orbit
Leq*	Equivalent continuous noise level (4db exchange rate)
LET	Linear energy transfer
LiOH	Lithium hydroxide
LOS	Line of sight
LP	Load package
LTA	Lower torso assembly
m	Meter
Maser	Microwave amplification by stimulated emission of radiation
Max	Maximum
mb	Millibar
MDAC	McDonnell Douglas Astronautics Company
MeV	Mega electron volts
MFR	Manipulator foot restraint
mg	Milligram
Mi	Mile
MIL	Military
Min	Minimum, (also) Minute
MISTC	Man inside the can - used for GEO EVA enclosure
MHz	Mega hertz
MLI	Multilayer insulation
mm	Millimeter
mmHg	Millimeters of mercury - used to indicate pressure level
MOTV	Manned orbital transfer vehicle

ACRONYM/ABBREVIATION	DEFINITION
MPAC	Multipurpose applications computer
mph	Miles per hour
MSC	Manned Space Center (JSC)
MSFC	Marshall Space Flight Center
MSIS	Man-Systems Integration Standard
MTBF	Mean time between failure
MU	Millimicron
MUX	Multiplexer
mw	Milliwatts
MW	Microwaves
N_2	Nitrogen
NASA	National Aeronautics and Space Administration
NAV	Navigation
Nc	Convective heat transfer coefficient
NC(Curve)	Noise criteria curve
NCRP	National Council on Radiation Protection and Measurements
Ne	Neon
NIOSH	National Institute for Occupational Safety and Health
NIR	Non-ionizing radiation
nm	Nanometer (10^{-9} meters); (also) nautical miles
NOAA	National Oceanic and Atmospheric Administration
NORAD	North American Air Defense
NTU	Nephlometric turbidity units
O_2	Diatomic oxygen
O	Oxygen
OASPL	Overall sound pressure level
OB	Octave band
OBS	Operational bioinstrumentation system
OMV	Orbital Maneuvering Vehicle
OR(Event)	Ordinary proton event

ACRONYM/ABBREVIATION	DEFINITION
ORU	Orbital replacement unit
OSHA	Occupational Safety and Health Administration
OTC	Over the counter
OTV	Orbital transfer vehicle
oz	Ounces
P	Proton
P_A	Partial atmosphere
P4SR	Predicted 4-hour sweat rate
PCM	Pulse Code Modulation
PEO	Polar Earth orbit
PFR	Portable foot restraint
pH	Measure of acidity
PLSS	Primary life support system, (also) Portable life support system
PNL	Panel
psi	Pound per square inch - static pressure
PSIA	Pounds per square inch - absolute pressure
PSIL	Preferred speech interference level
Pt/Co	Platinum/cobalt color measurement
PTS	Permanent threshold shift
PTZ	Pan, tilt, zoom
Q	Quality factor
qs	Body heat storage index
r	radius
Ra	Radium
RAB	Rigidizing attachment boom
rads	Radiation dose absorbed by tissue
RBE	Relative biological effectiveness
Rcl	Total heat transfer resistance
RDA	Recommended dietary allowance
R_e	Earth radii
REM, rem	Roentgen equivalent man

ACRONYM/ABBREVIATION	DEFINITION
RF	Radio frequency
RFI	Radio frequency interference
RFPG	Radio frequency protection guide
rms	Root-mean-square
RMS	Remote manipulator system
RTG	Radioisotope thermoelectric generator
s	Second
SAA	South Atlantic anomaly
SAE	Society of Automotive Engineers
SAFE	Solar Array Flight Experiment
SAT	Satellite
SAR	Scientific absorption rate
SCR	Solar cosmic radiation
SDMS	Standards Database Management System
sec	Second
SEP	Solar energetic particles
SIL	Speech interference level
SMF	Space medical facility
SPE	Solar particle event
SPF	Specific pathogen free
SPL	Sound pressure level
sq	Square
Sr	Strontium
SS	Space Station
SSA	Space suit assembly
Stbd	Starboard
STD	Standard
STL	Suppressor T lymphocyte
STP	Standard temperature and pressure
STS	Space transportation system
Sv	Sievert (radiation dose unit of measure)
SYS, Sys	System

ACRONYM/ABBREVIATION	DEFINITION
tb	Weighted mean body temperature
TBD	To be determined
TBT	Total body temperature
tc	Core temperature
TDRSS	Tracking and Data Relay Satellite System
THURIS	The Human Role in Space
TLV	Threshold limit values
TM	Telemetry
TMG	Thermal micrometeoroid garment
Tmrt	Mean radiant temperature
TOC	Total organic carbon
TON	Threshold odor number
torr	A unit of pressure equal to 1.316 x 10^{-3} atmosphere (Torricelli)
TPAD	Trunnion pin attachment device
Tr	Skin temperature
TTN	Threshold taste number
TTS	Temporary threshold shift (hearing)
TTS2	Temporary threshold shift measured 2 minutes after exposure
TV	Television
U, u	Micron
UCD	Urine collection device
USRA	Universities Space Research Association
UV	Ultraviolet
UVR	Ultraviolet radiation
VCR	Video cassette recorder
VDT	Visual display terminal
VOX	Voice-operated transmission
W	West
WASK	Work area safing kit
WB	Wet bulb temperature

ACRONYM/ABBREVIATION	DEFINITION
WBGT	Wet bulb globe temperature
WD	Wet/dry index
WFI	Water for injection
W/S, W-S	Workstation
Xe	Xenon
Z	Ultra heavy nuclei

TABLES AND FIGURES

1.0 INTRODUCTION TO EVA IN GEO - AN ENVIRONMENTAL DESCRIPTION

The environmental variables at GEO are often influenced by periodic changes in solar activity, meteor streams and operational position within the GEO corridor. The following description is for mean values of parameters unless otherwise noted (Brown, 1973; Ford, 1986; Hord, 1985; Lockheed, 1986; McCormack, 1987; Letaw, 1986; Chobotov, 1983; Stassinopoulos, 1980; Vernov, 1975; and Smith, 1983).

Distance from the Earth's Center:

- o 42,400 km
- o 26,347 statute mi
- o 22,280 nautical mi
- o 6.6 R_e (Earth radii)

Distance above the Earth's Equator:

- o 35,900 km
- o 22,308 statute mi
- o 19,393 nautical mi

Circumference of Orbit:

- o 266,400 km
- o 165,543 statute mi
- o 193,759 nautical mi

Orbital Velocity of Geostationary Objects:

- o 11,024 kmh
- o 6,850 mph
- o 5,949 knots

Earth Characteristics from GEO:

- Global Albedo: .39
- Earth Incident Radiation Heating: 4.73 watt/M^2/hr (1.5 Btu/ft^2/hr)
- Albedo Heating: 0 to 8.5 watt/M^2/hr (0 to 2.7 Btu/ft^2/hr)

Solar Constant:

- 1.36×10^6 Erg/cm^2/sec
- 1.95 cal/cm^2/min
- 430 Btu/ft^2/hr
- 1355.6 watt/m^2/hr

Potential Exposed Surface Temperatures:

- 116° to 394° K
- -157° to 121° C
- -250° to 250° F

Thermal Effects on Materials at GEO/Probable Exposed Surface Temperatures, Al:

- 140° to 335° K
- -133° to 62° C
- -208° to 143° F

Gravity:

- 10^{-6} g (20 m sphere centered at center of mass)

Gas Pressure:

- 10^{-15} N/cm^2
- 10^{-13} mb

Gas Density:

- 10^{-23} g/cm^3

Vacuum:

- 10^{-12} torr

Kinetic Temperature:

- $2 \times 10^{5\circ}$ K
- Ions: $10^{4\circ}$ K to $5 \times 10^{4\circ}$ K
- Electrons: $10^{5\circ}$ K to $5 \times 10^{5\circ}$ K

Solar Wind Flux (mean, quiet conditions):

- 10^8 cm^{-2} s^{-1}

Solar Wind Velocity at GEO:

- 300-400 km/s (mean, quiet conditions)
- 1600 km/s (with strong perturbations of the solar plasma)

Sun Azimuth Angle, O:

- 0 to 360 degrees

Sun Angle:

- +15 to -15 degrees

Earth Eclipse:

- 0 to 72 minutes

Defocusing Effect of Earth's Magnetic Influence at GEO:

- .635 times flux

Space Debris/Probable Artifact Density (Mass Flux):

- 10^{-8} debris objects > $3m_r/km^3$ at ± .2° latitude
- $< 10^{-9}$ debris objects > $3m_r/km^3$ at ± 5° latitude

Radiation Environment:

- Galactic Cosmic Radiation Ranges
  - 85% protons - 90% protons
  - 14% alpha particles - 9% alpha particles
  - 1% heavy ions
  - Proton Flux at Sunspot Minimum
    - 4.1 protons/sq cm/sec (E > 100 MeV)
    - 2.3 protons/sq cm/sec (E > 1 GeV)
  - Proton Flux at Maximum Solar Activity
    - 1.6 protons/sq cm/sec (E > 100 MeV)
    - 1.2 protons/sq cm/sec (E > 1 GeV)
- Incident Electromagnetic Radiation

Radio	$< 3 \times 10^9$ Hz
Microwaves	3×10^9 to 3×10^{11} Hz
Infrared	3×10^{11} to 3.75×10^{14} Hz
Visible	3.75×10^{14} to 7.5×10^{14} Hz
Ultraviolet	7.5×10^{14} to 3×10^{16} Hz
Soft X-Rays	3×10^{16} to 2×10^{17} Hz
Hard X-Rays	2×10^{17} to3 $\times 10^{19}$ Hz
Gamma Rays	$> 3 \times 10^{19}$ Hz

- Electron Flux
  - 5×10^4 electrons/cm^2/sec
  - (Maximum at 160° W longitude, minimum at 70° W longitude. Maximum at noon, minimum at midnight.)

- o Trapped Electrons (E >2 MeV)
  3×10^9 electrons/sq cm near local noon
  1×10^9 electrons/sq cm near local midnight
  (Varying by several orders of magnitude over several days)
- o Trapped Protons (E >1 MeV)
  Negligible
- o Solar Particle Events
  Protons and Alpha Particles from KeV to > 100's MeV
- o Bremsstrahlung - Energetic electrons that emit "braking radiation" as they move through matter, such as shielding material
- o Free Radicals - Negligible at GEO

Orbit Types:

- o Geosynchronous - Revolves about the Earth at the same rate the Earth rotates
- o Geostationary - Revolves about the Earth over the same Earth position
- o Geosynchronous Geostationary - The rate and the position of the orbit are both matched to an Earth reference.

2.0 GEO EVA MISSION REQUIREMENTS SURVEY/DEFINITION

From current mission descriptions (Lockheed, 1986, Ford), there appears to be an underlying assumption that EVA support will be available at GEO. The most frequently cited EVAs are servicing, repair, and maintenance of orbital equipment and satellites. It is generally recognized that significant changes in the ways in which EVA is conducted and modifications to EVA support systems will have to be realized before EVA at GEO becomes a reality. Indeed, the expense of conducting EVA at GEO - the expense of new techniques and equipment - is frequently given as a reason to consider EVA only as a last resort in GEO environment operations.

The following sections of this technical report describe the conditions of EVA at GEO, a set of tasks in a probable mission, and mission constraints.

2.1 Unique GEO EVA Environmental Considerations

The principal environmental consideration that is unique to conducting EVA at GEO is radiation. Discussed in detail in Sections 3.2.15 and 4.5, radiation poses the most serious threat to manned missions into GEO, and the most severe design constraints on EVA support equipment.

Using the Naval Research Laboratory's galactic cosmic radiation model, a JSC analysis of the protection afforded by the current Shuttle EMUs indicates that some radiation exposure limits are exceeded in a single 8-hour EVA at GEO (see item number 3, page 15 for the details of this analysis).

Another characteristic is the absence of the Schumann resonance electromagnetic field. Since this field is

present at the surface of the Earth and perturbations of this normal field have been shown to cause changes in physiological performance, the absence of the Schumann field in space is hypothesized by some researchers to cause a change in the nature of neuroelectric information processing in the brain. This is particularly true of timing phenomena, and thereby contributes to, complicates, and enhances the possibility of neurophysiological maladaptation for long-term, deep space activities.

Humans normally function in a terrestrial electromagnetic (EM) environment comprised of three components: an extremely low frequency (ELF) resonant cavity field, an electrostatic field, and a magnetostatic field. In GEO, personnel will be removed from the Earth-ionosphere resonant cavity environment (predicted by Schumann in 1952) which is responsible for the terrestrial electrostatic field and the ELF frequencies. The existence of this low level, global, uniform, continuous cavity resonance EM field was experimentally verified in 1960 (Galejs, Baker and Wagner). The third field, the magnetostatic field, is negligible beyond 10 Earth radii.

The third factor to be considered is a function of the stationary characteristic of the GEO orbit. GEO missions will be capable of maintaining constant communication with fixed Earth stations once the MOTV reaches geostationary position.

The fourth consideration, solar illumination will also be different from the phases experienced in LEO, with longer periods of solar illumination available for working. The additional lighting will also influence EVA design requirements in forms of visor assemblies, portable lighting, and day and night cycles of work and rest.

2.2 GEO EVA Task Definition

- The NASA Advisory Council's Task Force on the Role of Man in Geosynchronous Earth Orbit identifies no nominal GEO/EVA requirements in the near term (1987).

- The advanced automata programs being pursued by NASA are envisioned to be applied eventually to routine GEO operations such as servicing, resupply, and repair as an alternative to EVA.

- The historical precedents for employing EVA in recovering from system failure and executing contingency operations, coupled with the potential for automated system failure or functional mission inadequacy, suggest that for critical missions EVA will be the only available method of mission recovery.

- The mission model of EVA at GEO developed for this study is based on an automated servicing spacecraft which has become physically entangled with the satellite it was servicing. The resultant mass, under limited attitude control, poses a threat to other satellite traffic in the geosynchronous plane.

- The model assumes the development of some major technology to support both the teleoperated and manned servicing of GEO missions, namely an automated or teleoperated servicing spacecraft capable of performing dexterous manipulation during servicing, and a manned orbital transfer vehicle (MOTV) capable of GEO insertion and supporting a crew of three for up to 15 days. A concept sketch for an MOTV is included for discussion in Figures 2.2-1 and 2.2-2.

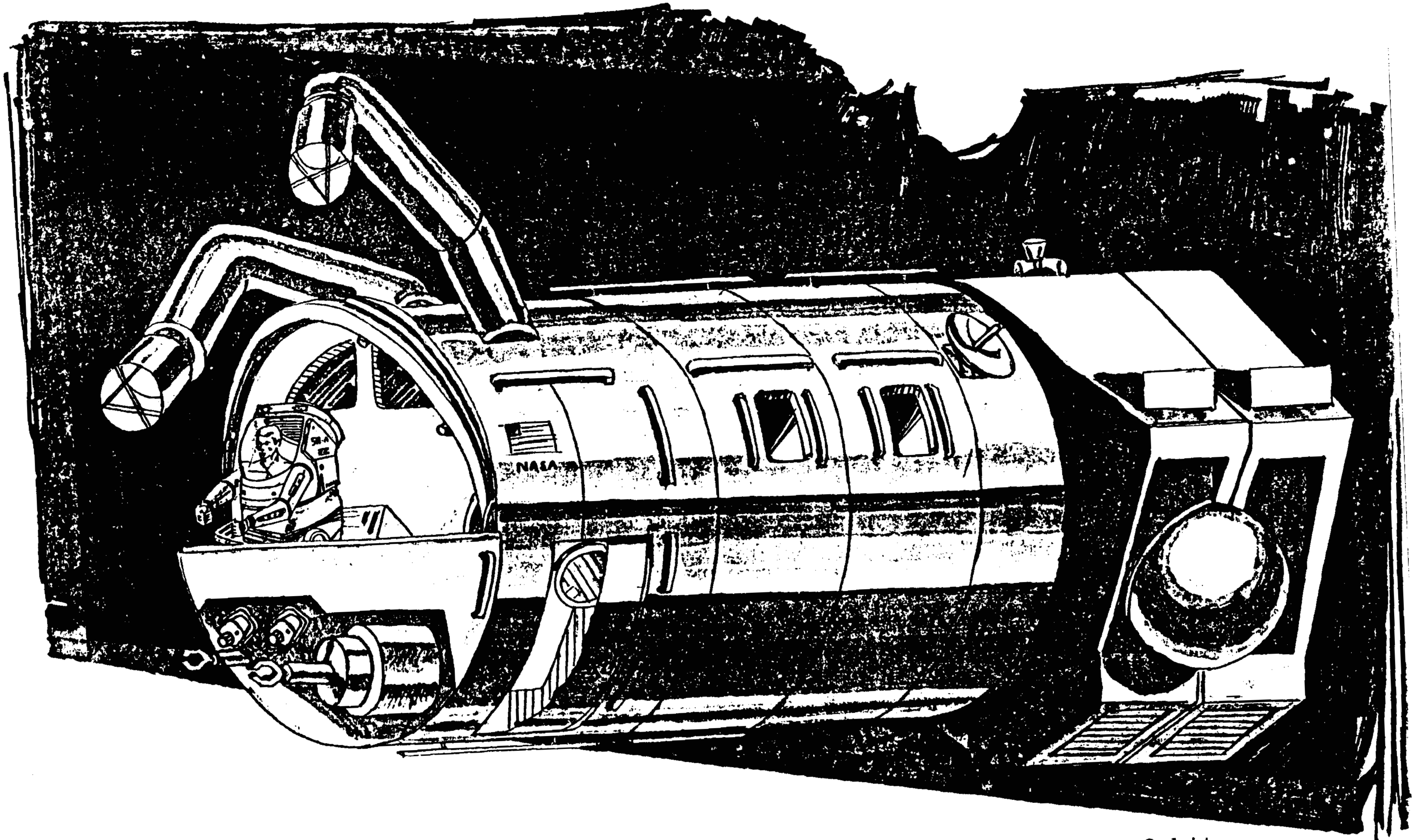


Figure 2.2-1 Concept of an MOTV to Support EVA at Geosynchronous Earth Orbit

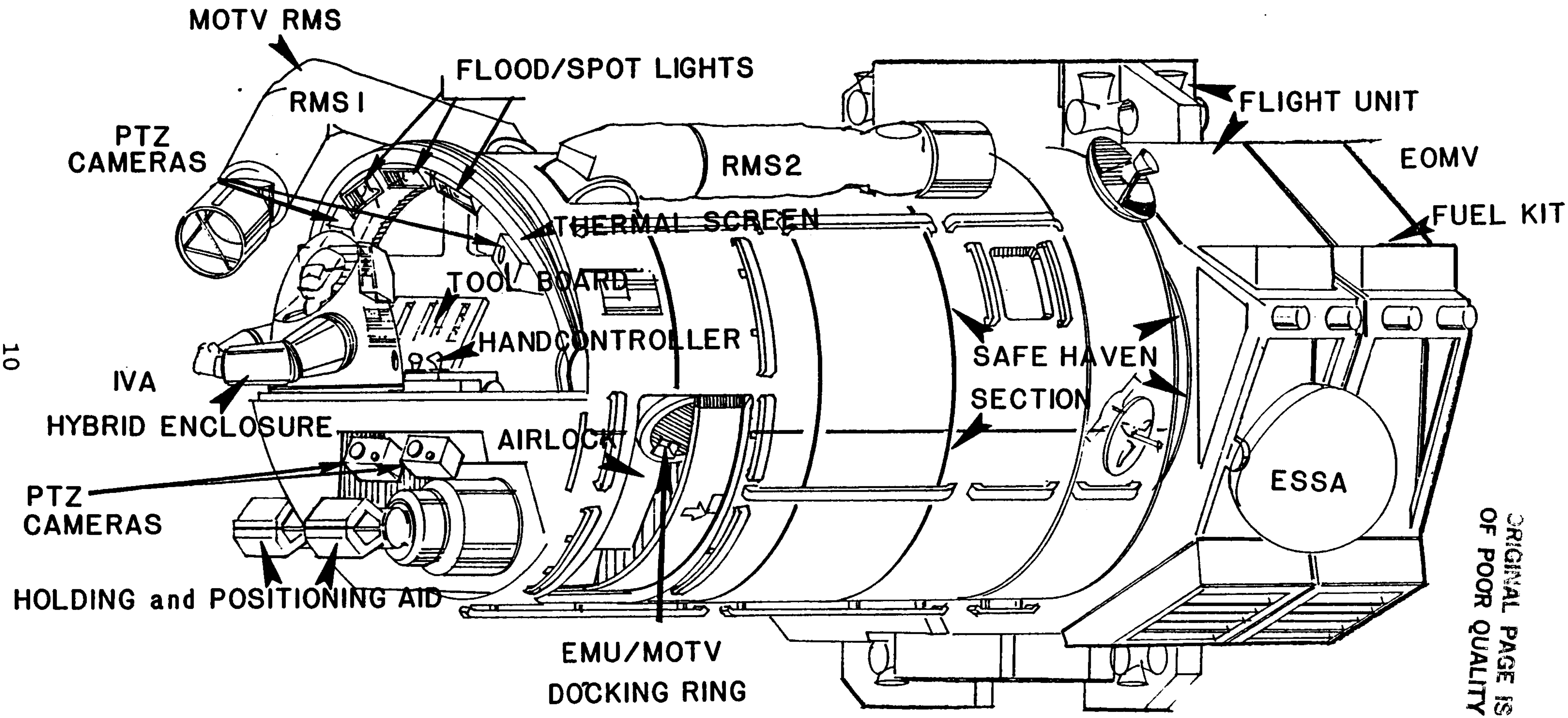


Figure 2.2-2 Concept of an MOTV to Support EVA at Geosynchronous Earth Orbit

2.3 GEO EVA Mission Scenario Development

The following reference mission description for extravehicular activity in geosynchronous Earth orbit (GEO) was developed to support the requirements of the following sections from the contract statement of work:

- 3.1.1 - EVA Task Definition
- 3.1.2 - EVA Mission Scenario Development
- 3.1.3 - Unique EVA Environmental Considerations
- 3.2.1 - Mission Operations Requirements
- 3.2.1.1 - EVA Scenario Definition

Based upon immediate GEO mission requirements and the ongoing development of teleoperated servicers, there are no explicit requirements to send EVA crewmembers on a scheduled basis to the GEO environment. Therefore, the GEO reference mission is based upon the failure of an automated servicing mission and the required intervention of human capabilities on-site to recover from the failure.

Two assumptions of technology development which underlie the reference mission: first, that the OMV can be equipped with a teleoperated servicing front end - automated orbital servicer, smart front end, or flight telerobotic servicer - for capture and manipulation of orbital articles; and second, that extra fuel kits will be developed to permit the OMV to execute GEO missions. These two developments are under study and could lead to an enhanced OMV, herein called the Enhanced Orbital Maneuvering Vehicle (EOMV) for the purposes of developing this GEO reference mission.

The capability to transfer humans from LEO to other orbits - specifically GEO - will be developed using a Manned Orbital Transfer Vehicle (MOTV). The particular design of this vehicle may be a man-rated OMV kit, a derivation of the crew

emergency rescue vehicle (CERV), or some specific vehicle designed to transfer and support humans in GEO. The crew support components of the system would have to be specifically designed to meet all of the requirements of human operations at GEO regardless of the propulsion approach developed. For the purpose of the design reference mission, this vehicle - propulsion and crew accommodations - will be referred to as the MOTV.

GEO REFERENCE MISSION SCENARIO

Initial GEO Reference Mission

One of the several dozen satellites parked in geosynchronous Earth orbit has failed in such a way that its attitude and orbit are threatening other satellites in the GEO plane. The satellite is drifting, and due either to communication or controller failures, the space operations group is not able to correct the situation through ground or Space Station control commands. Over a period of months the satellite will become a physical hazard to other satellites in GEO so the space operations managers elect to mount a retrieval or repair mission using an EOMV equipped with a propulsion kit to enable it to go to, and return from, GEO. The EOMV is also outfitted with multiple manipulators, video, lighting and other subsystems which will be capable of supporting teleoperated rendezvous, docking, repair, and servicing, or retrieval and return to Space Station.

The preparation of the EOMV at Space Station for this initial mission may well require EVA as described in the three final reports defining Advanced EVA requirements for Space Station. Such LEO EVA is not within the mission description required for this GEO EVA study.

The EOMV is deployed from Space Station and its control is passed off to ground control for its flight to GEO. At GEO, the EOMV rendezvous and docks with the failed satellite. The EOMV mission controllers initiate diagnostics on the satellite systems and conclude that on-orbit repair can be accomplished through replacement of a single ORU controller based in the flight control unit. The automatic sequence to effect this is transmitted to the EOMV which in turn commences the removal-replacement task.

During the EOMV tasks, an electrical brake fails on one of the manipulator arms and efforts to retract the arm from the satellite are unsuccessful. This failure results in an entanglement of the EOMV and the satellite. However, through use of the EOMV thrusters, the mission controllers are able to keep the two entangled vehicles stabilized in GEO.

The risks of returning the EOMV to the Space Station with its failed satellite are assessed and, due to the risks associated with deorbit, this option is eliminated. Mechanical forces on the manipulator arm, open access doors and the loose equipment would pose too great a physical hazard to execute a safe return to Station. The EOMV mission is declared failed and the Mission Director selects a manned GEO mission using EVA as the best approach to safely disentangle the two vehicles and repair the failed satellite and the EOMV manipulator brake. EVA tasks are planned and the crew undergoes training at Space Station for the mission. Appropriate simulations are conducted on Earth to validate the approach and operations. The options that involve Advanced EVA technologies, such as a new class of EMU crew enclosure and a hybrid IVA/EVA workstation, are compared to a more conventional approach in Figure 2.3-1.

FAILED SATELLITE AND OMV PHYSICALLY ENTANGLED

ADVANCED TECHNOLOGY APPLICATIONS

EVA DAY 1 — 10 hrs

- 2 EVA Crew Members Egress MOTV:IVA Crew Uncradles Arm
- EVA Transfer to Satellite/EOMV Kits
- Visual Inspection/Diagnostics
- MOTV Arm Grapples Satellite (HPA)
- EVA Deact/Passiv. Satellite
- EVA Deact/Passiv. EOMV
- EVA Separation EOMV and SAT
- EOMV Activated, Stand-off and Station Keep
- EVA Detailed Inspection of Grappled Satellite; Assess Repair Options
- EVA Translate, Ingress MOTV

ADVANCED TECHNOLOGY OPTIONS

IVA SCENARIO

DAY 2 — 8 HRS

- o Satellite on Arm HPA with MOTV Work Envelope
- o Remote Repairs IVA ½ Suit Repairs from MOTV
- o SAT Check-out, Verify and Release

EVA SCENARIO

- o 2 EVA Crew Work on HPA/ Satellite
- o Satellite Checked Out, Verify and Release

EXISTING EVA TECHNOLOGY USED

EVA DAY 1 — 8 HRS

- 2 EVA Egress MOTV
- 2 EEU Attachment
- Access Workstation/Tool
- IVA Crew Member Uncradles Arm
- EVA Translate to SAT/EOMV
- EVA Deact/Passiv. Satellite
- EVA Deact/Passiv. EOMV
- Stow Tools/W-S EEU Detach/Refurb
- 2 EVA Ingress MOTV

EVA DAY 2 — 8 HRS

- 2 EVA Egress MOTV EEU Attachment
- Access Workstation/Tool Kits
- Manual Separation of Satellite/EOMV
- Re-enter Airlock
- EOMV Reactivated, Standoff and Station Keep
- EVA Inspection of SAT, Assess Repairs
- Stow W/S, Tools
- Detach Refurb EEU
- Ingress MOTV

EVA DAY 3 — 8 HRS

- Prepare for EVA Satellite Repair
- ORU Change Out, SAT Check-out, Verify and Release
- Post EVA

Figure 2.3-1 Considered Options for EVA Scenario at Geosynchronous Earth Orbit

GEO EVA Repair and Recovery Mission

Assumptions

The MOTV/EVA mission to GEO is activated. The assumptions made for this mission are as follows:

1) MOTV is outfitted with a habitability module with living and working provisions for a minimum of three crewmembers.

2) Mission duration is limited to four days (100 hours) and provisions are onboard the MOTV to support 15 days of activity and life support.

3) EVA is accomplished using enclosures with operating pressures which are greater than 8 psia and require no pre-breathing in preparation for EVA. The enclosures also provide adequate radiation protection for the GEO environment.

   The nominal radiation environment at GEO is more intense than at LEO and, as a consequence, additional provisions to protect the EVA crewmembers must be made. Protection from nominal radiation can be accomplished by reducing exposure time, increasing the protective shielding, or a combination of the two. While the details of GEO radiation are dealt with in Sections 3.0 and 4.0 of this report, the radiation protection afforded by current EVA enclosures is briefly discussed here.

   The JSC Radiation Analysis of Candidate EVA Space Suit Material Layups Memorandum (May, 1987) provides millirem dose percentile limits for particular portions of several space suit assemblies. The computed GEO

figures, based on the Naval Research Laboratory's galactic cosmic radiation model, show that for the Space Shuttle suit (EMU) and the AX5 SSA, the highest radiation exposure occurs at the arms and legs. Indeed, for the current EMU, exposure at GEO to the arms and legs is approximately 120% of the dose limit for one 8-hour EVA. The AX5 SSA, without radiation protection, keeps exposure to about 10% of the permissable limit for a single 8-hour EVA. On the other hand, the exposure limits for the torso section of the Shuttle EMU were just over 9% and for the AX5 SSA, they were .24% for an 8-hour EVA.

Hands in the arms and gloves of an EVA enclosure is an essential capability of EVA crewmembers. Manipulation, stabilization, and translation are a few of the functions effectively performed by using the hands and arms. Portions of time spent in resting, lengthy communications, propelled translation, and data analysis do not require that the hands be used, however. Greater radiation protection could be afforded the EVA crewmembers if they were able to withdraw their arms within the torso area of the EVA enclosure. Additionally, if both legs could be surrounded by unitary enclosure protection, and the positioning and stabilizing capability of the feet and legs replaced with manipulators, even less exposure would be realized.

With the ability to withdraw the hands and arms into the torso area, other benefits, such as ease of eating, drinking, and personal care, and the ability to operate secondary controls inside the enclosure, occur. A concept sketch of an EVA enclosure that provides for the removal of the hands to the torso section and

enclosure of the lower body in a unitary shell is discussed below.

4) At least two types of EVA enclosures are envisioned. The first is an integral part of the MOTV and is essentially an anthropomorphic suit from the waist ring up while attached to the MOTV at the waist ring, as shown in Figure 2.2-2. The second is a detachable EVA enclosure which could either be of an anthropomorphic design or could be a lower body canister and an upper body anthropomorphic design. The detachable, deployable EVA enclosures would have integrated attitude control and translation capabilities. The "Man-Inside-the-Can" (MISTC) is a strawman concept of an EVA enclosure and is shown in Figures 2.3-2 and 2.3-3.

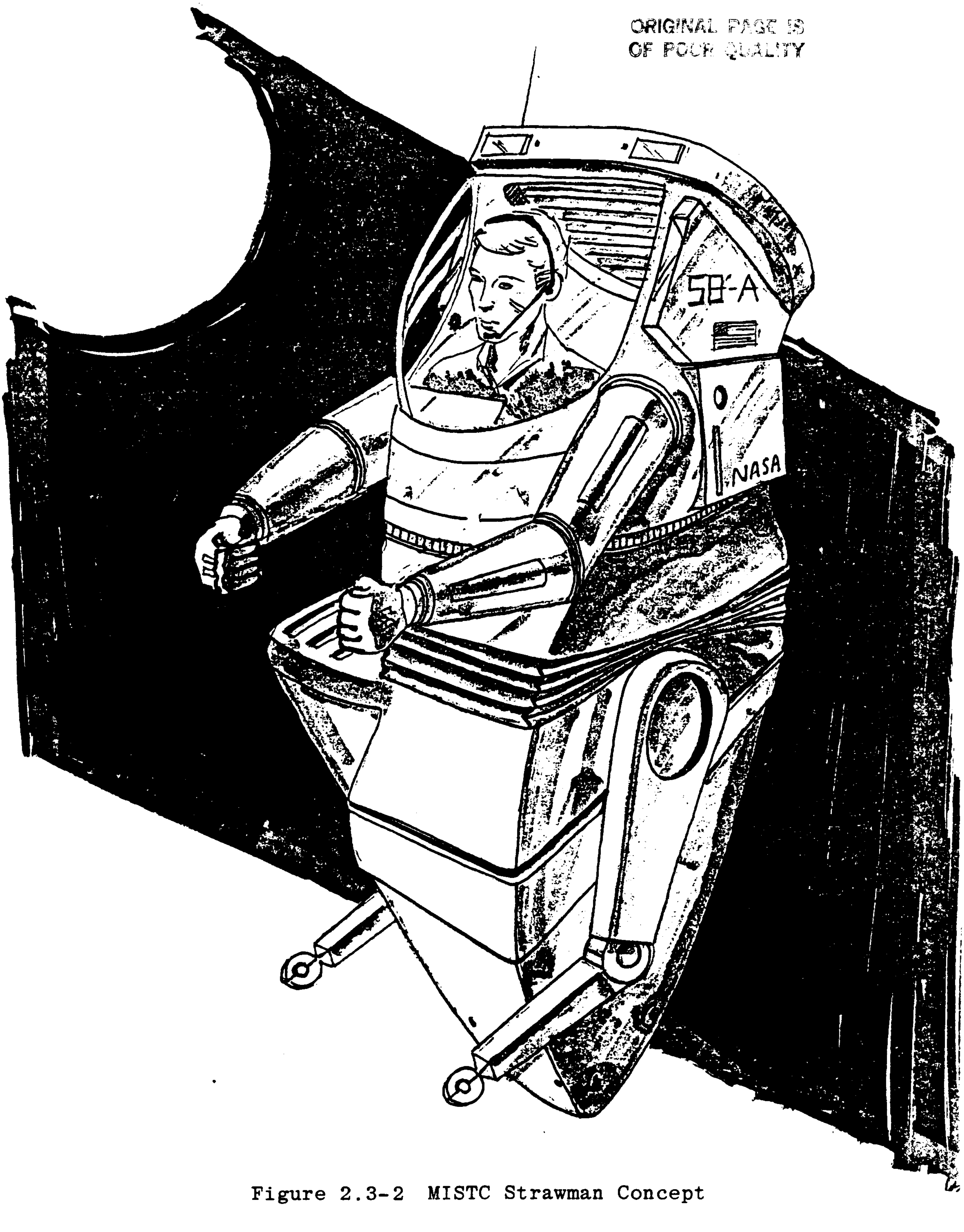


Figure 2.3-2 MISTC Strawman Concept

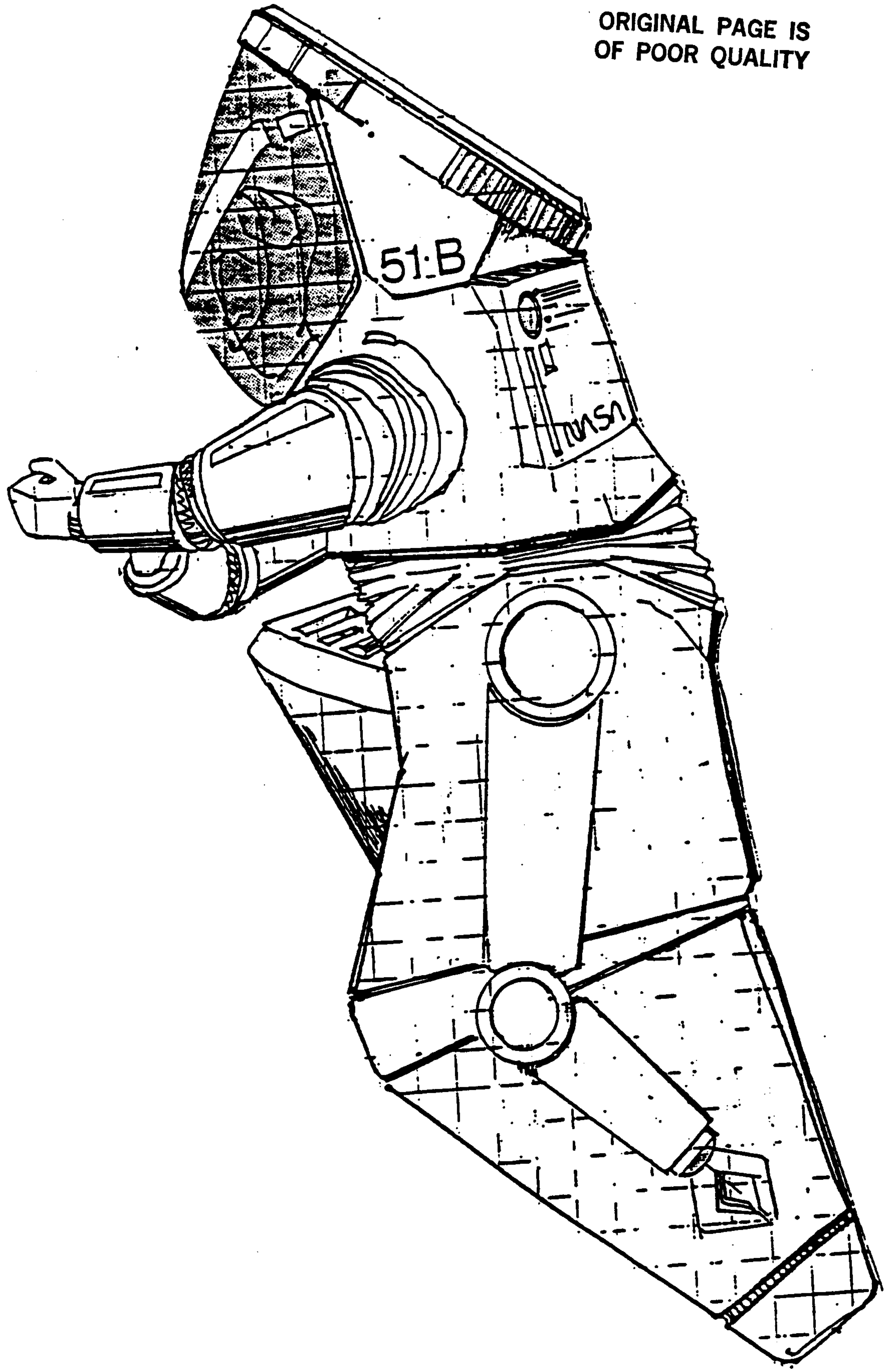


Figure 2.3-3 "Man-Inside-the-Can" (MISTC) Strawman Concept

5) There will be sufficient room inside both types of EVA enclosures for a crewmember to rest, eat, drink, handle body waste management, and extract his or her arms for operational and personal requirements.

6) There will be a wide range of vision through the EVA enclosure canopy or helmet, and provisions for vision enhancement such as magnifiers, binoculars, and displays.

7) The EVA enclosures will have multiple external manipulation modes including gloved hand and arm, and mechanical manipulators with a selection of prehensors and tools.

8) Sizing and preoperational activities are accomplished pre-mission, but the EVA enclosure permits quick servicing or maintenance on site.

9) The EVA enclosures are capable of supporting a total of 10 hours of EVA work. This recommendation by the technical team assumes some capabilities beyond the Space Station EMU life support system. The 10-hour support does not include an additional 30-60 minutes of contingency reserves.

10) The attachment and berthing mechanisms for the EVA enclosures permit rapid docking and don/doff (ingress/egress) in the event of environmental anomalies such as solar flare or event caution and warning.

11) The MOTV provides protection and safehaven in the event of fast radiation from a solar event, including hard and soft x-rays, ultraviolet, and gamma radiation equivalent to 20 g/cm^2 Al.

12) Hyperbaric capabilities can be provided by a stowable device(s) on the MOTV.

13) Emergency return to LEO from GEO should be considered to protect from hazards associated with electron and proton arrival. Currently this is not feasible during SPE where the maximum or peak flux arrives at two hours, so on-orbit protection must be provided by the MOTV.

The following mission timeline was developed from existing servicing timelines and anticipated activities associated with the MOTV and MISTC.

Reference Mission Timeline

	Time
o Fully equipped MOTV undocks and separates from Space Station	T = 00:00:00
o Phasing maneuvers for GEO transfer burn and preparation for transfer burn	T = 06:00:00
o MOTV at GEO Rendezvous	T = 12:00:00
o Crew configures Spacecraft and equipment for GEO operations. Unstow, prepare, assemble and check-out	T = 15:00:00
o Crew eats and sleeps	T = 24:00:00
o Crew eats and prepares for first EVA	T = 27:00:00
o Perform first EVA - detailed steps 1-76a	
o Eat, clean EVA enclosures	T = 34:00:00

At the conclusion of the EVA Day 1, EOMV remains at station keeping 1 Km from MOTV. Satellite remains attached to MOTV by HPA.

o Sleep, eat	T = 46:00:00
o Prepare for second EVA	T = 48:00:00
o Perform second EVA - detailed Steps 77-101	
o OMV remotely reactivated, commanded to stand-off and station keep	T = 51:00:00

GEO/EVA REFERENCE MISSION SCENARIO USING
MODIFICATIONS TO EXISTING SYSTEMS

(Scenario assumes the EVA crew with EEU capabilities, port and starboard EVA docking ports on the MOTV, and an IVA commander who controls the MOTV and MOTV manipulators and holding and positioning aids.)

TASK	EVA CREW Port	EVA CREW Stbd	IVA Commander	CUM TIME EVA (by day)
1. Preparation of EMUs and Onboard Equipment	00:45	00:45		
o Don EMUs	00:10	00:10		
1a. System Check-out of RMS/HPA-			00:30	
Uncradle, Deploy			00:15	
2. Leave Airlock		00:01	00:01	00:01
3. Translate to Tool Storage	00:01	00:01		00:02
4. Obtain Basic Tool Kits	00:05	00:05		00:07
5. Translate to EEU/FSS	00:01	00:01		00:08
6. Lock into EEU	00:02	00:02		00:10
7. Translate to Workstation (MFR)	00:01			00:11
8. Lock onto EV Workstation	00:02			00:13
9. Translate to SAT/EOMV Vicinity (.50 M)	00:03	00:03		00:16

TASK	EVA CREW Port	Stbd	IVA Commander	CUM TIME EVA (by day)
10. Visually Inspect SAT/EOMV	00:05	00:05		00:21
11. Voice Com Verify Systems State	00:01			00:22
11a.P/S Standoff (25 m)				
12. Maneuver MOTV in Range			00:05	00:27
13. Grapple EOMV with MOTV RMS			00:02	00:29
14. Verify Dock (SYS/Visual)			00:01	00:30
15. Translate to Work-site	00:01	00:01		00:31
16. Attach Workstation to Worksite (EOMV/SAT/RMS-2)	00:08	00:08		00:39
17. Ingress Workstation	00:01			00:40
18. "S" Crew Station Keep				
19. "P" Access MI Cutter	00:01			00:41
20. Cut Access to SAT PWR PNL	00:04			00:45
21. Secure MLI	00:02			00:47
22. Stow MI Cutter/ Access Screw Remover Pwr Tool	00:01			00:48
23. Remove and Stow Screws 1 N=30	00:15			01:03
24. Remove Panel and Stow	00:04			01:07
25. Visually Inspect Power Subsystem	00:02			01:09
26. Safe Attitude Control	00:05			01:14

TASK	EVA CREW Port	Stbd	IVA Commander	CUM TIME EVA (by day)
27. SAFE COM/NAV	00:05			01:19
28. SAFE Internal Power	00:05			01:24
29. Verify All Systems Safe and Power Disconnected	00:10		00:10	01:34
30. "P" Voice Command to Reconfigure	00:01			01:35
30a.RMS at EOMV/ Translate	00:05		00:05	01:40
31. "S" Crew Trans to EOMV/Station Keep		00:02		01:40
32. "P" Positioned at EOMV	00:02		00:02	01:42
33. Access Tools	00:01			01:43
34. Unscrew/Open Access Panel at EOMV	00:03			01:46
35. Inspect Power Control	00:02			01:48
36. Disconnect Power Subsystems	00:03			01:51
37. Safe Manipulator Arms	00:05			01:56
38. Safe Attitude Control	00:05			02:01
39. Safe Power Distribution	00:05			02:06
40. Verify All Systems Safe and Power Disconnected	00:10		00:10	02:16

TASK	EVA CREW Port	Stbd	IVA Commander	CUM TIME EVA (by day)
41. "P" Voice Command IVA to Move MFR to SAT/EOMV Entanglement/ Translate	00:05			02:21
42. "S" Translates to SAT/EOMV		00:02		
43. "S" Establishes Restrained W/S		00:05		
44. "P" Sets Worksite Lighting				
45. "P" Access Tool Kit/Power Tool	00:03			
46. "P" Remove Cover Panel From Manipulator Braking Motors	00:30			02:56
47. "S" Receive/Restrain Cover Panel and Power Tool		00:01		02:57
48. "P" Manually Releases Braking Motor	00:10			03:07
49. "P" Access Tool Kit/Extraction Tool	00:01			03:08
50. "P" Applies Extraction Tool to Manipulator	00:05			03:13
51. "P" Unlocks Failed Manipulator and Extracts It from Satellite	00:30			03:43

TASK	EVA CREW Port	EVA CREW Stbd	IVA Commander	CUM TIME EVA (by day)
52. "P" Accesses Tool Kit/Stow Tools	00:02			03:45
53. "S" Transfers Cover Panel and Power Tool to "P"		00:02		03:47
54. "P" Reinstalls Braking Motor Cover Panel	00:30			04:17
55. "P" Retracts Manipulator Arm and Locks in Safe Position	00:30			04:47
56. IVA Deploys HPA and Grapples Satellite			00:15	05:02
57. "S" Verifies Grapple (EOMV Now on RMS, SAT on HPA)		00:01		05:03
58. "P" Manually Disengages EOMV Docking Device	00:30			05:33
59. "S" Releases Restrained Workstation		00:03		05:36
60. "S" Translates 5M Away from EOMV		00:01		05:37
61. "P" Manually Separates EOMV/SAT	00:10			05:47
62. S/P Observe Separation	00:02	00:02		05:49

TASK	EVA CREW		IVA	CUM TIME
	Port	Stbd	Commander	EVA (by day)
63. "S" Translates to Area of EOMV				
64. IVA Observes HPA and SAT During Separation			00:02	
65. S/P Visually Verify Separation and Report Such to IVA	00:01	00:01		05:50
66. Translate to EOMV, Set Up Worksite	00:05			05:55
67. "P" at EOMV Power	00:03			05:58
Reactivate Power Control Panel, Distribution and Attitude Control	00:03			06:01
68. "P" Replace Power Access Panel at EOMV	00:03			06:04
69. "P" Replace Tools/ Stow Tool Kit	00:05			06:09
70. "S" Translates to MOTV EEU		00:03		
71. "P" Egress Workstation/ Translate to EEU/ FSS/DOFF EEU	00:15			06:24
72. IVA Extends EOMV with RMS			00:01	06:25
73. IVA Verifies System Check-out of EOMV (with Ground)			00:10	06:35

TASK	EVA CREW Port	EVA CREW Stbd	IVA Commander	CUM TIME EVA (by day)
74. IVA Releases EOMV (EOMV Command to 1 km Standoff Via EOMV Controllers)			00:01	06:36
75. "P" Ingresses Port Airlock	00:10			06:46
75a."S" Ingresses Stbd Airlock		00:10		
76. "P" DOFFs EMU	00:10			06:56
76a."S" DOFFs EMU		00:10		
77. Preparation of EMU and Onboard Equipment	00:45	00:45		
o Don EMU	00:10	00:10		
78. IVA Prepare/ Checkout Forward Workstation Lighting			00:15	
79. S/P Leave Airlock	00:01	00:01		00:01
80. Translate Tool Stores	00:01			00:02
81. Obtain Servicing Tool Kit	00:10			00:12
82. Translate to EEU/ FSS	00:01			00:13
83. Lock into EEU	00:02			00:15
84. Translate to EVA Worksites	00:01			00:16
85. IVA Orient Satellite using HPA			00:10	00:26
86. IVA Deploy RMS with EVA Workstation			00:20	00:36

TASK	EVA CREW Port	EVA CREW Stbd	IVA Commander	CUM TIME EVA (by day)
87. Lock into EV Workstation	00:02			00:38
88. IVA Orients EVA Crewmember At Satellite	00:05		00:05	00:43
89. "P" Removes Tools from Servicing Kit	00:02			00:45
90. "P" Removes Failed Control System	01:00			01:45
91. Hands Control System to "S"	00:01			01:46
92. "S" Stows Failed System		00:02		01:48
93. "S" Removes New Control System		00:01		01:49
94. "S" Hands Control System to "P"		00:01		01:50
95. "P" Installs New Control System	01:30			03:20
96. "P" Verifies Installation/ Connection	00:20			03:40
97. "P" Reactivates Attitude Control	00:03			03:43
98. "P" Reactivates COM/NAV	00:03			03:46
99. "P" Reactivates Internal Power	00:03			03:49
100. "P" Verifies Power to All Systems	00:05			03:54

TASK	EVA CREW Port	EVA CREW Stbd	IVA Commander	CUM TIME EVA (by day)
101. "P" Commands IVA/ RMS Standoff	00:02		00:02	03:56

- o Stand-off 00:01:00 — T = 55:00:00
- o Begin checkout — T = 55:01:00
- o At T = 55:10:00 solar event warning from ground
- o Emergency translate and ingress to MOTV in less than 00:08:00 — T = 55:18:00
- o Preparation for safehaven configuration. less than (00:30:00) — T = 55:48:00

T = 61:48:00

Nominal work cycle to complete this mission without interruption by a SPE would be:

TASK	EVA CREW Port	EVA CREW Stbd	IVA Commander	CUM TIME EVA (by day)
102. Verification of Satellite Systems OK (Ground or IVA)			00:30	04:26
103. "S" Collects Failed System and Translates to Stowage		00:05		04:31
104. "P" Egresses RMS Workstation	00:01			04:32
105. "S" Stows Failed System		00:05		04:37
106. "S" Translates to EEU/FSS		00:02		04:39

TASK	EVA CREW Port	Stbd	IVA Commander	CUM TIME EVA (by day)
107. "S" DOFFS EEU		00:03		04:42
108. S/P Translates to Airlock	00:03	00:02		04:45
109. IVA Orients SAT for Release			00:03	04:48
110. Releases Satellite			00:01	04:49
111. S/P Enters Airlock-Repress	00:05	00:05		04:54
112. S/P DOFFs EMU Complete EVA Day 2	00:10	00:10		04:55

2.3.1 EVA Work Period Parameters

For a new generation of "hands-in" EVA enclosures, it should be possible for the crewmember to attend to waste management, eating and drinking, and rest periods. Given these accommodations, long periods of EVA will be preferred with rests between tasks based on task requirements. Environmental radiation exposure will determine sequential EVAs, as will the number of crewmembers available for EVA duty rotation. For a crew of three with minimum radiation exposure, two consecutive days followed by IVA would allow the crew to rotate EVA duty and produce the highest productivity with minimum crew.

2.3.2 EVA Duty Cycles

At GEO, the EVA duty cycle will be largely dependent upon the radiation exposure to the EVA crewmembers. For a nominal mission, adequate protection for multiple EVAs is afforded by the MISTC or other enclosure. With a three-person crew, each should be capable of performing the EVA and the IVA tasks so that crew rotation is possible on the GEO missions. This would permit a crewmember to work two EVA days and then complete one IVA day. This approach to rotating EVA duty has been confirmed by EVA-experienced crews as a reasonable one in view of the MISTC capabilities. Duty cycle rotation could be as follows:

	Mission Day							
	1	2	3	4	5	6	7	....N
Crewmember 1	I	E	E	I	E	E	I	....
Crewmember 2	E	I	E	E	I	E	E	....
Crewmember 3	E	E	I	E	E	I	E	....

2.3.3 EVA Workday Length

The limiting factor should be physiologically, not technologically, driven. Provided appropriate enclosure life support design and arm/hand assistance, the human should be able to perform over eight hours of EVA at GEO. Based on responses from questionnaires sent to EVA technical specialists, it was widely thought and reported that the EVA workday length should be extended beyond 8 hours to increase EVA productivity for GEO missions. The range of productive EVA appropriate to existing technology was from 6 hours to an upper limit of 12 hours, with most respondents reporting 10 hours as preferred. The basis for extending EVA beyond 10 or 12 hours was an absolute solution to the problem of arm and hand fatigue that crewmembers have experienced with the existing glove technology.

2.3.4 EVA Duration Optimization

Equipment technology should be a facilitating, not a limiting, factor. EVA at GEO is required or justified only when other means have failed or are inappropriate. Therefore, the equipment technology should meet the environmental protection and human physiological requirements and support a full period of productive EVA without resupply.

2.3.5 EVA Translation Considerations

There have been no identified requirements for translation at GEO which are different from those at LEO or in Space Station proximity.

The translation means should be considered in two ways: 1) structurally attached, and 2) freely. Free translation

might be manual or propulsive. Attached might be via RMS workstation, a structures attached trolley, or an extender or retractor.

2.3.6 EVA Rescue Capability

Both equipment and personnel should be able to be rescued by either IVA or EVA means.

The use of maneuvering capability and manipulators for recovery has been demonstrated in LEO. The MOTV, with its manipulators and mobility capabilities, should accommodate equipment and personnel rescue.

The standard practice of having two EVA crewmembers at the EVA worksite provides the primary rescue capability of a disabled crewmember. The rescuing crewmember must be capable of manuevering the disabled crewmember to the airlock docking ring and positioning him or her for mating with the MOTV. Once mated, the IVA crewmember will be able to extract the disabled crewmember from the MISTC enclosure.

The procedures developed for crew and equipment rescue in other Earth orbits should be applied to GEO operations.

3.0 GEO EVA HARDWARE DESIGN CRITERIA

3.1 GEO EVA Man/Machine Requirements

3.1.1 Unique Human Capabilities in GEO EVA

The ability to generalize knowledge and past experience to unique situations or previously unknown situations, and exert control based on that knowledge and experience is a capability that can be offered only by humans at any site. In most circumstances, especially those involving uncertainties, humans are more adept at making real-time situational assessments than are machines. Based on these assessments, humans are also more flexible in arriving at effective decisions as to how to deal with a problem or circumstance. Equally important, humans can improvise and "make-do" with available tools and materials to effect a solution to a novel problem. Section 6.1 provides an outline covering the technical issues associated with unique human capabilities and their application to EVA and EVA at GEO situations. Detailed man/machine tradeoffs need to be documented based on machine capabilities and reliability, task definition and knowledge, and specific human abilities.

3.1.2 Logistics

High reliability and redundancy in design should minimize spares requirements. Replacement modules should be the focus of hardware logistics. The logistics requirements for GEO missions could be reduced by focusing on regeneration and recycling technologies, eleviating some of the replacement and replenishment activity associated with consumables. Consumables for life support should be provided for the mission duration, plus the maximum duration of a GEO rescue turn-around mission, plus a fixed

consumables contingency based on mission safety factors. Consumables for non-life support should be provided for the mission duration.

3.1.3 Maintainability

Maintaining EVA hardware at GEO should be kept as simple as possible, focusing on modular exchange, simple cleaning, and easy adjustments while at GEO. Preventive and detailed maintenance should be accomplished at Space Station or on Earth.

System and Subsystem Maintainability: Based on crew experience, the most desirable features to enable efficient refurbishment are:

1. Ease of disassembly and reassembly,
2. Degree of modularity in design,
3. Commonality among different items and systems,
4. Ease of test, check-out, and verification after refurbishment,
5. User friendly techniques to perform fault analysis and diagnostic and corrective procedures or actions,
6. Efficient work station and restraints and appropriate tools and test equipment, and
7. An adequate inventory of spares and repair materials.

EVA Enclosure Resizing: For short, special-purpose missions the level of accommodation should be at the flight preparation stage. If enclosure suit resizing is required during flight, that is, at the working level, the procedure should be much easier than in the past, when it required a suit technician to refit. One aspect of suit sizing that has caused problems in the past is that suits fitted in one-g are too tight in the shoulders during flight due to the height increase in zero-g. This problem should be

minimized with the MISTC being sized at Space Station. One concept proposed for evaluation is employing internal, reconfigurable bags which could be inflated or deflated to accommodate different sizes and task requirements. Mechanically adjustable pedestals for the feet and mechanically adjustable seat and torso support could be another alternative.

EVA Hardware Servicing: EVA hardware servicing must be possible at the working level by the flight crew to preclude aborting costly missions because of inoperative EVA hardware. As the EVA crews become more specialized, they can be expected to develop the qualifications to perform servicing tasks of greater complexity, if the equipment has been designed to accommodate the work in a space environment.

Spares and Supplies: For EVA, onboard inventory of spares and supplies will build on previous experience, such as failure history, use of depletion rates, generic maintenance, and logistics supplies. The following recommedations would significantly contribute to EVA maintainability:

o Packaging and defining the components (ORUs) within devices, equipment, and systems in a way that considers
  (a) Past service performance, such as failure rates and MTBF, of the whole assembly or ORU,
  (b) Optimization of the replacement, verification and check-out task,
  (c) The weight and mass penalty of carrying along spares, and

- o Generating a general purpose supply kit for onboard fabrication. There have been several cases - Apollo XIII to STS - in which the crew has fabricated ingenious devices, conceived by both ground and flight crew, to satisfy a contingency need.

3.1.4 Hardware Servicing

Major support items such as EEUs, RMS, and HPAs should not require any scheduled servicing during the execution of a GEO mission. The requirement to perform scheduled servicing on major, proven support systems detracts from the productivity of the primary mission. Tools should not require calibration or adjustment. Portable power and cold gas replenishment should be on a modular servicing basis, such as the replacement of batteries and the exchange of gas tanks.

3.1.5 Cleaning and Drying

The EVA enclosure should permit a crewmember to clean all interior spaces with a swab or suction tool. Enclosure cleaning requirements should be minimized through the use of disposable or cleanable undergarments or liners.

The detailed cleaning of individual sections of the MISTC or other EVA enclosure should be accomplished at Space Station prior to and after the GEO mission. During the GEO mission period, the nominal cleaning and drying should consist of the introduction of a neutral-scent biocide throughout the interior of the MISTC, cleaning the interior of the helmet visor, and the application of an antifogging agent to the visor. Drying should be through a forced-air mechanism which can remove all moisture from the enclosure between EVAs.

Cleaning of the interior of the enclosure after contamination with body wastes, spilled food or water, or other off-nominal wastes should be accomplished through the MISTC/MOTV docking port with a suction tool which can reach all interior spaces of the MISTC. The volume of the MISTC concept will permit IVA manual cleaning, if necessary to overcome significant contamination, of most of the interior.

3.1.6 Caution, Warning, and Check-Out

The caution and warning systems of the MISTC and MOTV should be similar in all operational respects to the systems used for space suits and Space Station configuration at the time for efficiency in use and effective transfer of training among crewmembers.

Check-out of the MISTC and its support systems should be accomplished from the enclosure prior to leaving the spacecraft. Check-out systems should be self-contained in the enclosure and provide automatic fault and out-of-tolerance data, independent monitoring, and display of corrective action required by the crew. The monitored variables, as well as the parameters calculated from combinations of them, should be displayed in the MOTV and in the MISTC. If the spacing between the EVA display and the observer's eyes is less than near-normal vision, optical correction needs to be made on the display. Synthesized speech, which is capable of conveying more detailed information, should be considered in addition to warning tones. Expert systems to suggest corrective measures should also be a design consideration.

The general requirements for caution, warning and check-out are as follows:

- o Caution and warning tones and synthesized speech formats should be common with those of Space Station for efficiency in use and cross-training of crews.

- o All caution and warning audio tones should be distributed by the audio system. Suggested protocols are as follows:
  - CLASS I - CREW EMERGENCY (not switchable)
    Siren tone (fire and/or smoke)
    Klaxon tone (pressure decay)
  - CLASS II - HARDWARE FAULTS
    Dual alternating tones, 400/1024 Hz
  - CLASS III - SOFTWARE LIMIT FAULTS
    Single tone, 500 Hz
  - Caution and warning can also be through dedicated warning lights and special displays

- o Caution and warning indicators can be:
  - Auditory tones
  - Synthesized speech
  - Alphanumeric displays
  - Combinations of the above.

  Alphanumeric information can be displayed on dedicated displays, heads-up displays (HUDs), or helmet-mounted displays (HMDs).

- o Caution and warning should be displayed both to EVA and IVA crewmembers.

- o Caution messages should be displayed, with tone, whenever one or more monitored variables of the MISTC exceeds one or more of its limits.

- o Warning messages should be displayed, with tone, whenever a safety-critical limit has been exceeded.

o Automatic Check-out of pressurization system integrity, primary and emergency oxygen supply, CO_2 removal system, thermal cooling loop, communications subsystems, data display systems, and wiring and power continuity should be accomplished prior to an EVA and verified by the IVA and the EVA crewmember.

All classes of caution and warning tones should be distributed by the audio system. Class I tones should not be capable of being defeated. Caution and warnings for the MISTC should be autonomous and not depend upon processing in the MOTV for actuation. An appropriate system reset should be provided in the MISTC.

3.1.7 Communication Requirements

The communications requirements for advanced EVA in GEO are basically the same as those established for Space Station. EVA differences are associated with the routing of communications and the fact that GEO provides a fixed position from which to communicate with Earth stations. When beyond the communication jurisdiction of Space Station, the MOTV should communicate directly with Earth (in accordance with JSC 30000 II); consequently, channel configuration and frequencies should match those of Earth systems. As a result of the adverse orientations of the tracking and data relay satellite system (TDRSS) and other relay antennas and intermittent lines of sight to Space Station, the utility of these configurations is minimized. Consequently, relay of signals to Space Station from GEO will be through Earth stations.

It is recommended that the mission control center functions for a GEO mission will be Earth-based. This recommendation is based on the limited number of personnel on the station and the extremely high cost of their time, as well as the

larger availability of satellite repair database information on Earth.

Equipment and procedures should be provided to protect the MOTV systems and crew from power radiated by the satellite being approached or serviced. Similarly, radiations from the MOTV must not interfere with or damage the systems of the satellite.

Since the MISTC will be operating in the proximity of satellite payloads which are transmitting considerable power or which could be EMI susceptible, it may be desirable to use umbilical or hardwired channels to prevent interference.

Radio frequency (RF) threat detection and display should be provided through the communications system as part of the caution and warning requirements. Unless operational procedures can absolutely insure avoidance of RF radiation patterns, the design of the MISTC must provide flexible shielding in the garment and RF choked couplings at the mobility joints. A conductive but transparent faceplate must be developed and integrated into the system. Elements of the system outside of the enclosure must be hardened and all wiring harness penetrations of the MISTC must be protected from RF interference. The task is especially difficult because wavelengths to be rejected may be less than a centimeter and very high effective incident radiated power (EIRP) levels are expected. In any case, it is desirable to develop an RF threat sensor which indicates the approximate wavelength band and level of the incident energy.

Voice-activated audio in the EVA enclosure should be provided for communication among EVA crewmembers and between EVA and the on-site base ship - in this case the MOTV.

It has been recommended by members of the technical team that a private EVA-to-EVA communication channel be available. This is not a unanimous recommendation, and currently there are not such provisions. A trade study dealing with the positive and negative aspects of such a link should be considered. Video information should be provided to and from the EVA crew as a means of giving the crew detailed procedures and graphics, and giving the base ship visual information on which to make expert or support decisions. Detailed data display should be a part of the video display system. The transmission path to Earth is not changing while on station in GEO. It is suggested that technical and procedural data to be used during EVA might be stored in a redundant high density, subject addressable, mass memory such as a CD laser disk. The location of this storage may be either on Earth or in the MOTV. The EVA display for this data must have sufficient size and resolution for precision text and graphics.

EVA and MOTV transmission link parameters must be set at values which will not damage or interfere with nearby GEO satellites. Similarly, RF energy, radiated from visited GEO satellites, to which crewmembers could be exposed must be evaluated for crew and EVA/MOTV equipment exposure hazards. Shielding and special circuit protection may be required, or the use of hardwires or umbilicals may be a design solution.

"Snoopy"-Cap COMM-Carrier can be replaced in the EVA assembly with a speaker/microphone system. If a non-noise-cancelling microphone is used, it may be desirable to move it away from the area of highest sound pressure, which is just in front of the mouth. There is great latitude in its placement, but it should be placed on the enclosure perhaps at the lower edge of the visor. If it is moved too far to the sides or rear, the high frequency energy might be lost. Redundant microphones might be placed on each side of the

front of the enclosure. They would also serve to maintain a more constant signal level as the head is turned. The effects of spacing geometry on frequency response must be evaluated.

One or more speakers may be mounted in the enclosure. Speaker operation is complicated by the presence of duplex transmission links which transmit into and out of the helmet at the same time. Special electrical and acoustical features must be incorporated in order to prevent the loudspeaker output, which is picked up by the microphones, from being transmitted with the outgoing speech. This configuration will place greater constraints on in-suit cooling fan and pump noise.

The communications requirements associated with the MOTV should include the following:

o The RF channels should be readily assignable on a requirement basis, compatible with Space Station communications system, before or during a mission with automatic allocation of required bandwidth.

o Sufficient channels should be available to communicate full-duplex, simultaneously, with two EVA units while providing two simultaneous duplex channels to Earth.

o Two duplex channels should be provided to the Space Station when within 37 km of it. Each carrier should accommodate any combination of the data functions.

o The communication systems should be configured to provide maximum autonomy to the MOTV crew under normal conditions, with extensive interaction with Earth sources of expertise and data systems.

- o Voice commanded functions should be provided for speech inputs from both EVA and MOTV. TV camera manipulation is a typical EVA task which should be voice commanded.

- o All communication signal processing functions required for EVA must also be provided for MOTV.

- o Selected audio and video sources should be combined within the MOTV for processing prior to recording or transmission.

- o For audio recording and playback, two simultaneous record and playback tracks should be provided on each of two redundant recorders.

- o A voice-operated transmission (VOX) record function should be provided to minimize no-speech tape usage.

- o Recordings should contain a time code which remains with the text if it is re-transmitted.

- o Flexibility should be provided to select and combine signals for recording and playback to any outgoing communications link.

General communication requirements for supporting EVA at GEO can be summarized as follows:

- o Automatic gain control (AGC), VOX, digitizing, coding, decoding, multiplexer (MUX), demultiplexer (DEMUX) and packetizing are typical signal processing functions which should be performed within the EVA communication system.

- o The voice-operational channel should be one full-duplex assigned channel.

- o A voice emergency channel should provide for one full-duplex fixed channel.

- o Crewmember switchable encryption and de-encryption should be provided for privacy or security reasons.

- o Telemetry - MISTC systems and biomedical data should be packetized and combined with voice for transmission to the MOTV.

- o Video generated by MISTC mounted or hand-held cameras should be digitally encoded and packetized with voice, telemetry and commands prior to transmission on a single assigned carrier from the EVA to the MOTV.

- o HUDs or HMDs should provide for text, graphics, and video to be displayed inside the helmet enclosure of the EVA crewmember.

- o At least one high quality video/voice track should be provided for video recording and playback.

- o Recordings should contain a time tag which remains with the video/audio complex if it is re-transmitted.

- o Combinations of audio from any source may be mixed and embedded in the recorded video complex. Video may be recorded from any onboard or receiver source. It may be played back to any transmitter including the EVA link, where it may be displayed in the HUD.

- o Mass data storage of text, graphics, and any necessary procedures and technical information should be accomplished in redundant, rapid-access, mass media, such as laser disks.

3.1.8 Contamination

Contamination requirements must be dealt with in terms of those inside the EVA enclosure and those outside the enclosure.

Potential sources of contamination inside the EVA enclosure include the EVA crewmember, the water and food supply for the crewmember, and the enclosure subsystems, such as electrical, thermal control, and atmosphere control.

Within the EVA enclosure, the primary concerns are contamination due to system failures, such as an electrical short, loss of coolant water, or contamination of the breathing air. Any of these failures would require an immediate abort of the EVA, as well as an immediate remedy of the situation. The EVA enclosure must be designed to detect these types of failures and the resultant contamination, as well as provide for contaminant suppression and emergency back-up to enable the crewmember to return to the base ship.

The crewmember as a source of contamination exhales CO_2, expires and perspires moisture, sloughs off hair and skin - especially during strenuous activity - and discharges body waste liquids, gases, and solids.

The atmosphere control system of the enclosure must be designed to keep the CO_2 levels below an STP equivalent of 1.01 kPa (7.60 mmHg) during any EVA and, optimally, should keep it at an STP equivalent of 0.03 kPa (0.23 mmHg). Water vapor should be removed to preclude helmet and visor fogging.

Small physical contaminants should be drawn away from the helmet area and filtered out at the foot of the EVA

enclosure. This includes food particles, hair, skin cells, and similar small artifacts, as well as flatus.

Body waste contaminants should be dealt with first at the waste management subsystem level. For urine and feces, dedicated subsystems are required in the enclosure. For vomitus, a containment bag should be provided. In the event that any of these body wastes escape from the primary control subsystem, they must be directed away from the helmet area so as not to interfere with the airflow, life support system, or communications and control systems. The same requirement applies to loose food particles and water supply contamination.

These requirements are summarized here for GEO EVA and are not necessarily unique requirements in that the same control of contamination must exist for other EVAs. The MISTC concept does permit some added flexibility for in-suit contamination management and recovery, such as retrieving loose food, "mopping" or otherwise wiping up liquids, and inserting a mouthpiece breathing apparatus in case of atmosphere contamination.

The sources of external contamination at GEO are also similar to those found in other orbital EVAs. These include solids, such as multi-layer insulation fibers, and liquids, such as fuels. No GEO-peculiar factor was identified.

Typical expected contaminants and their limits were identified in Space Station Advanced EVA Studies and are summarized as follows:

o Initial Atmosphere - as in Space Station

- o Typical particulate contaminants
  - Dust (0.3 u to 30 u dia.)
  - Lint (40 u to 50 u dia.)
  - Metal Filings (30 u to 500 u dia.)

- o Possible Hazardous Fluid Exposure
  - Hydrazine propellant
  - Monomethylhydrazine propellant
  - Nitrogen Tetroxide Oxidizer
  - Ammonia external loop coolant
  - Various Freon coolants [Grumman, 1985]

- o Particulate Contaminants
  - Limit to less than 0.1 mg/cubic meter
  - Use gloves and tools that minimize the release of lint, dust and metal shards

- Trace Contaminants
  - Limit contaminants to the following maximum levels:

Contaminant	Maximum Allowable Level
Families of Compounds:	(mg/cubic meter):
Alcohols	10
Aldehydes	0.1
Aromatic hydrocarbons	3
Esters	30
Ethers	3
Halocarbons	
Chlorocarbons	0.2
Chlorofluorocarbons	24
Flourocarbons	12
Hydrocarbons	3
Inorganic acids	0.08
Ketones	29
Mercaptans	2
Oxides of nitrogen	0.9
Organic acids	5
Organic nitrogens	0.03
Organic sulfides	0.37
Specific Compounds:	
Ammonia	17
Carbon monoxide	500
Hydrogen cyanide	1

[McDonnell Douglas, 1986]

- Decontamination
  - Accomplish as close as possible to the source of contamination
  - Initiate procedures external to airlock, if possible

- Human Wastes
  - Observe established waste management/containment procedures
  - Observe good personal hygiene
  - Clean, disinfect and dry MISTC in accordance with established practice

- GEO Satellite Contact
  - Repair of GEO satellites may involve contact with unidentified and/or undefined contaminants
  - Use decontamination procedures appropriate for anticipated contaminants

- Atmospheric Drag
  - Do not rely upon drag to help clear particulates from the work area as done in LEO. This effect is absent in GEO.

3.2 GEO EVA Physiological/Medical Requirements

3.2.1 Anthropometric Sizing Accommodations/Dimensional Limits

No mission unique requirements to support GEO EVA have been identified as far as crew anthropometry, physiological changes, or human dimensional limits are concerned. The characteristics of the MISTC, on the other hand, provide the opportunity to explore several alternatives to accommodating individual anthropometric differences, as well as accommodating task requirement differences.

The MISTC permits in-suit hand operations and this in turn implies a range of motion inside the enclosure, which must be reduced during operations which are performed with hands and arms in the gloved mode. A requirement to restrain the

EVA crewmember within the MISTC during such operations does exist.

The lower portion of the MISTC will require crew-reconfigurable supports to accommodate the full range of heights of EVA crewmembers. In addition to foot height adjustment, lower leg and thigh supports are required to support and stabilize the crewmember during operations. The MISTC itself will be capable of being repositioned at the worksite through manipulator movements.

During EVA manual operations, the crewmember will have to be supported at the arm and hand enclosures of the MISTC to prevent sliding around in the MISTC. An adjustable webbing or internal inflatable bladders could provide such support.

Consideration should be given to internal sizing of the can dimensions to the crew through inflatable bladders which can be adjusted after donning and during tasks, or through a cooling garment that has inflatable bladders.

The general requirements to support individual anthropometric differences include:

o Adjustable foot positions within the MISTC

o Reconfigurable lower leg support

o Reconfigurable upper leg support

o Buttocks support

o Reconfigurable chest and back support to permit "hands-in" MISTC activities as well as support for the crewmember when he or she has both hands in the MISTC arm enclosure.

3.2.2 Metabolic Profiles

In establishing metabolic profiles for EVA, it is meaningful to summarize previously identified factors which influence metabolism.

The discussion of metabolic profiles will be divided into six categories:

1. Impact of Planned EVA Hardware
2. Proposed Atmospheric Conditions for EVA
3. Impact of Prior Exposure/Conditions on EVA
4. Human Factors
5. Work Requirements Associated with Primary Mission
6. Ancillary Work Requirements

3.2.2.1 Impact of Planned EVA Hardware

Factors associated with hardware design that affect metabolic costs during EVA must be considered. The design of the proposed EVA enclosure (either fully or partially anthropomorphic, tethered/untethered, part of the MOTV or separate) considered with such a workstation include the actual oxygen costs associated with operation, changes in efficiency due to the suit constraints, differences in efficiency due to the fit of the suit to individual EVA participants, and types of tasks and tools to be used during EVA.

3.2.2.2 Proposed Atmospheric Conditions for EVA

The atmosphere present in the MOTV and the MISTC will affect accurate determinations of EVA-associated metabolic profiles. Obviously, the weightless nature of travel to and from the SS, in the MOTV site and during EVA will affect task performance in many ways. Maintenance of body position

is changed in the weightless environment and task performance generally involves decreased efficiency over normal Earth, except possibly in cases of load carrying. These factors affect the energy requirements of EVA. Additionally, such factors as the oxygen and carbon dioxide levels in the MOTV, MOTV workstation and EVA enclosures during rest, times of low activity and exercise may affect the metabolic activity of EVA participants. In addition, the effects of the presence of particulates and organic compounds in the inhaled air on metabolism should be considered.

Thermal conditions will also have an impact on the efficiency and metabolic costs of a given activity. Humidity within the MISTC enclosure will affect the metabolism of EVA crewmembers, both directly due to thermal effects and indirectly due to possible visor fogging, decreases in efficiency of work performance and accelerated appearance of fatigue.

Another factor of concern is the operating pressure within the EVA enclosure. This affects mobility of the EVA participant and is particularly important when considering the pressure within the gloves since this will have a direct bearing on the efficiency with which the gloves can be used; i.e., a higher glove pressure reduces efficiency, and vice versa.

3.2.2.3 Impact of Prior Exposure/Conditions on EVA

The condition, both physical and psychological, in which EVA participants enter the EVA mission will have an effect on metabolic profile development. Among the factors that should be considered are such things as the deconditioning effects of extended SS stays prior to EVA; differences that might exist between the SS, the MOTV, and the EVA enclosure

atmospheres that might impact on metabolism during EVA; nutritional status of EVA participants; and physical conditioning and training programs for EVA that would be accomplished prior to the EVA mission. The effect of prolonged exposure to microgravity on basic regulatory functions may be a factor. Although some evidence exists to support the assumption that relatively short-term exposure to microgravity does not significantly affect basal metabolism, the effect of extended exposure is unclear. The level of physical fitness at which the EVA participants enter the EVA scenario is particularly important. Deconditioning effects associated with prolonged space stays can be expected to include the breakdown in skeletal and heart muscle protein and bone mass, a decrease in strength levels, and decreases in endurance. These factors mean that long duration EVA participants may be required to perform in the EVA scenario at greater percentages of their maximum abilities than they would if they had been in space only a few days. This means that fatigue will set in earlier and that efficiency of task performance will necessarily suffer if deconditioning effects are marked and no compensating conditioning programs have been implemented.

3.2.2.4 Human Factors

Human factors, as used here, are those factors which are related to the human element rather than the restraints imposed by the EVA hardware and space environment. Establishment of accurate metabolic profiles will be affected by the age and gender of the participants: Older individuals have a lower basal metabolic rate than younger ones, and probably have different metabolic reactions to imposed stress; women generally have lower metabolic rates, even when adjusted for size, than do men. Additionally, there are interindividual variations in metabolic rates, both for basal and stress conditions, that must be

considered when developing the ranges for expected metabolic profiles. Psychological reactions to the space environment and to EVA in particular may play an important role in determining metabolic profiles for EVA. Interindividual differences in metabolic responses to possible EVA scenarios must be considered when determining metabolic profiles. Whereas one person may react strongly to normal and emergency situations associated with EVA, another might perceive the situation to be less threatening. Therefore, the metabolic responses to such stressors will probably vary considerably between individuals.

3.2.2.5 Work Requirements Associated with Primary Mission

When determining metabolic profiles for EVA, the work required to perform the primary mission during the projected EVA scenario and potential contingency scenarios is a large portion of estimated metabolic costs. The specific activities performed will require estimates of metabolic costs to participants which will need to be adjusted for expected efficiency levels, fatigue factors, and conditioning levels. Determination of metabolic profiles associated with primary mission work will require consideration of such factors as the metabolic requirements associated with mobility (propulsion and maneuvering) to get both to and from the MOTV and during actual task performance; egress and ingress from the MOTV; personal requirements of eating, drinking, and perhaps waste management; and the use of tools to disentangle the satellite from the EOMV.

3.2.2.6 Ancillary Work Requirements

Aside from work associated with performance of the primary EVA mission, there are many ancillary tasks associated with EVA that have an impact on metabolic costs. Some factors to

consider under ancillary work are the travel time to and from SS to get to the EVA scenario, preparation time aboard the MOTV for EVA task performance, sleeping and eating time, personal hygiene activities, cleaning of the MOTV and EVA enclosures, and any servicing of the EVA and MOTV enclosures that might be required. During each of these time periods, both basal metabolic functions and physical activity associated with ancillary task performance will have to be accounted for in any metabolic profile analysis of EVA. A factor which might often be overlooked in determining the metabolic costs of a given activity are those associated with recovery from physical exertion. Since strenuous physical exertion can raise the basal metabolic rate for 24-48 hours, and since the EVA participants can be expected to have exerted themselves rather strenuously, the metabolic profiles of recovery should be considered in any determination of metabolic costs.

3.2.2.7 Past Experience

The following summaries provide metabolic rates from past missions and maximum and minimum rates for specific periods of EVA based on current design standards:

- o Average Metabolic Rates during EVA:
  - Apollo = 929 Btu/hr (272 watts, 234 kcal/hr)
  - Skylab = 912 Btu/hr (267 watts, 230 kcal/hr)
  - Shuttle = 779 Btu/hr (228 watts, 196 kcal/hr)

- o Based on previous NASA missions, the Environmental Control System should support:
  - Average metabolic activity rate of 990 Btu/hr (290 watts, 250 kcal/hr) or 1.86 watts/lb (1.6 kcal/hr/lb) for duration of EVA

- Maximum metabolic activity rate of 1984 Btu/hr (581 watts, 500 kcal/hr) or 3.72 watts/lb (3.2 kcal/hr/lb) for 15 minutes and 1598 Btu/hr (468 watts, 403 kcal/hr) or 3.02 watts/lb (2.6 kcal/hr/lb) for 1 hour
- Minimum metabolic activity rate of 256 Btu/hr (75 watts, 65 kcal/hr) or 0.49 watts/lb (0.42 kcal/hr/lb) for 1 hour

o Extraordinary systemic fatigue should not occur after 10 hours of EVA at average rate of 990 Btu/hr (290 watts, 250 kcal/hr) or 1.86 watts/lb (1.6 kcal/hr/lb).

3.2.3 Suit Operational Pressure Level

The resting metabolic rate for a 70 kg individual under one-g conditions is approximately 300 cc/min in terms of O_2 consumption ($\dot{V}O_2$) and 250 cc/min of CO_2 production ($\dot{V}CO_2$). If the pulmonary ventilation is not pathologically or environmentally affected, then the alveolar partial pressure of CO_2 (P_ACO_2) is regulated at between 4.7 and 5.3 kPa (35 and 40 torr). At 1.0 atmosphere (14.7 psia) this requires a ventilation of about 6 to 10 liters/min and results in a partial pressure of O_2 in the lungs (P_AO_2) of about 14.1 kPa (106 torr) as calculated from the alveolar equation (1) shown below:

Equation 1:

$$P_AO_2=(P_B-47)F_IO_2-P_ACO_2[F_IO_2+(1-F_IO_2)/(\dot{V}CO_2/\dot{V}O_2)]$$

[Rahn and Fenn, 1955]

where P_B is barometric pressure in torr. Since the metabolic rate during work in EVA enclosure is not anticipated to be more than 5 times the resting level, i.e., 1.5 liters/min for $\dot{V}O_2$ or $\dot{V}CO_2$, it would seem acceptable to

maintain a lower F_IO_2 in the enclosure and, therefore, a lower P_AO_2. This will economize O_2 supply or total pressure maintenance systems. A value of 11.3 kPa (85 torr, 1.64 psia) would seem acceptable (the normal value a mile-high city such as Denver or Albuquerque where Pb=84.0 kPa or 630 torr or 12.2 psia). The O_2 fraction (F_IO_2) required to accomplish this is 0.181, rather than the 0.209 which is available in normal air. In order for P_AO_2 to be maintained at a value of 11.3 kPa (85 torr, 1.64 psia), F_IO_2 must be increased as the operational pressure in the enclosure is lowered and this can be calculated by equation 1 as shown in Figure 3.2.3-1. Technical and mechanical considerations must then be given to the choice of maintaining a higher total pressure with lower F_IO_2 or vice versa.

For GEO operations in which time is critical, the following requirements should be met to reduce unproductive time as a function of suit operational pressure:

- Space Station pressurization 101.3 kPa (14.7 psia)
- MOTV pressurization 101.3 kPa (14.7 psia)
- Use "no pre-breathe pressurization" 57.2 kPa (8.3 psia)
- Provide 30 minutes of purge operation in a secondary oxygen supply.
- Provide emergency pressurization to maintain MISTC at a minimum pressure of 41.4 kPa (6.0 psia) for 30 minutes minimum.

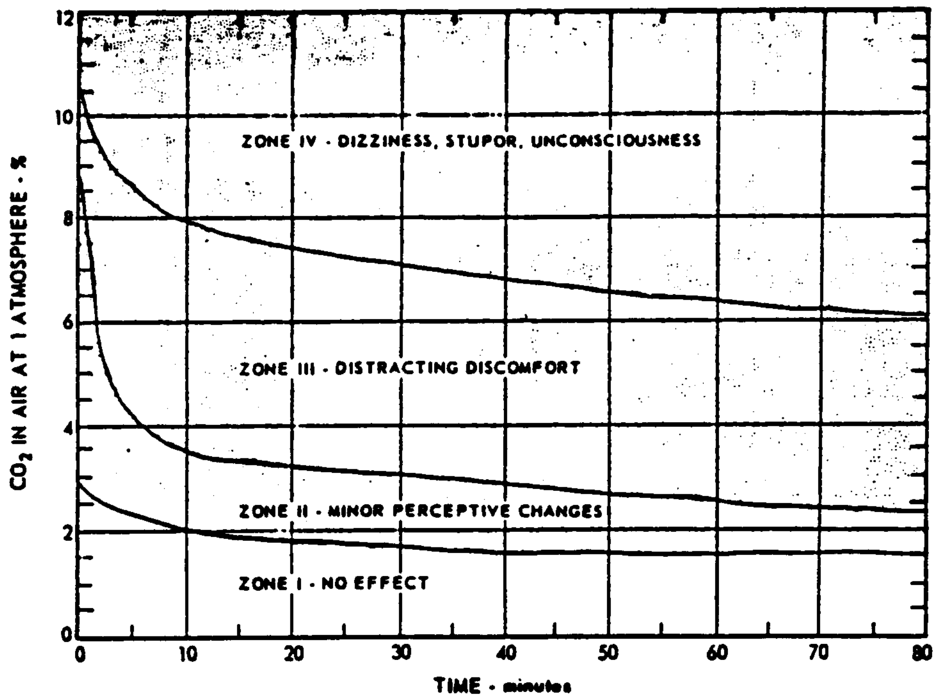
3.2.4 CO_2 Levels

It is imperative that a "foolproof" CO_2 scrubber be used to maintain CO_2 levels at less than 0.9 kPa (7.0 torr, .02

psia) in the MISTC (Lovelace Foundation, 1971). Accumulation of CO_2 in the enclosure will result in two serious consequences, (a) a progressive rise in pulmonary ventilation resulting from the rise in P_ACO_2 and arterial PCO_2 stimulating the chemoreceptors (Figure 3.2.4-1) and (b) visual and auditory hallucinations, headache, nausea, asphyxic sensations, sweating and loss of consciousness which occur with increasing prevalence as concentrations and time of exposure increase (Figure 3.2.4-2).

If the space around the crewmember in the enclosure has a volume equal to the body, about 70 liters (Lovelace Foundation, 1975), a 10% level for a resting individual will be reached after only 28 minutes if the CO_2 scrubber fails totally. If the individual is working at three times the resting metabolic rate in manipulative tasks (Table 3.2.4-1), then this level will be reached in less than 10 minutes. If a crewmember is working at the maximum metabolic activity rate 581 watts (500 kcal/hr), then this level will be reached in about 4 minutes without an active CO_2 removal system. In order to allow for 10 hours of work at an average of three times the resting metabolic rate, a total of 0.250 x 3 x 60 x 10 = 450 liters or 20.2 moles of CO_2 will be produced which must be effectively scrubbed to prevent the concentration from exceeding 2% at 1.0 kPa (7.3 torr, .15 psia)). Even at this level there will be significant CO_2 storage in the body (Lovelace Foundation, 1971) which will take an appreciable time to be eliminated when returning to the CO_2-free environment of the MOTV. For example, a 10- hour exposure to a 0.9 kPa (7.0 torr, .02 psia) CO_2 environment will cause an increase of approximately 3.3 liters in body CO_2 stores (Farhi, 1964). This is about a 50% increase in the natural CO_2 stores in the body.

Figure 3.2.4-1 Symptoms and Thresholds of Acute and Chronic Carbon Dioxide Toxicity



This chart presents the general symptoms common to most subjects when exposed for the times indicated to mixtures of carbon dioxide in air at a total pressure of 1 atmosphere. In Zone I, no psychophysiological performance degradation, or any other consistent effect, is noted. In Zone II, small threshold hearing losses have been found and there is a perceptible doubling in depth of respiration. In Zone III, the zone of distracting discomfort, the symptoms are mental depression, headache, dizziness, nausea, "air hunger," and decrease in visual discrimination. Zone IV represents marked deterioration leading to dizziness and stupor, with inability to take steps for self-preservation. The final state is unconsciousness. (Roth, 1968)

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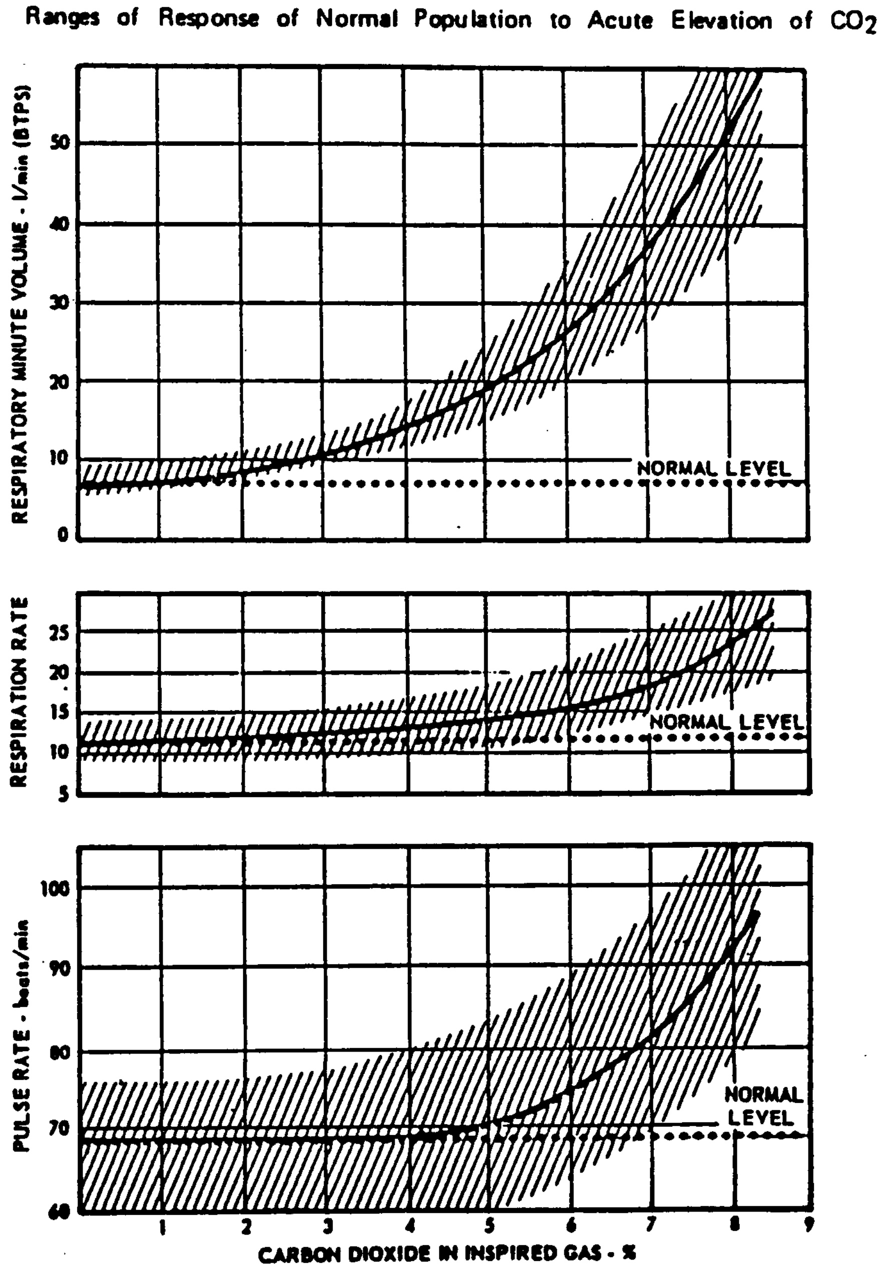
Figure 3.2.4-2 Cardiorespiratory Response to Carbon Dioxide



The immediate effects of increased CO_2 on pulse rate, respiration rate and respiratory minute volume are shown for subjects at rest. The hatched areas represent one standard deviation on each side of the mean. To convert percentage of CO_2 to partial pressure, multiply fraction of CO_2 by 760 mmHg.

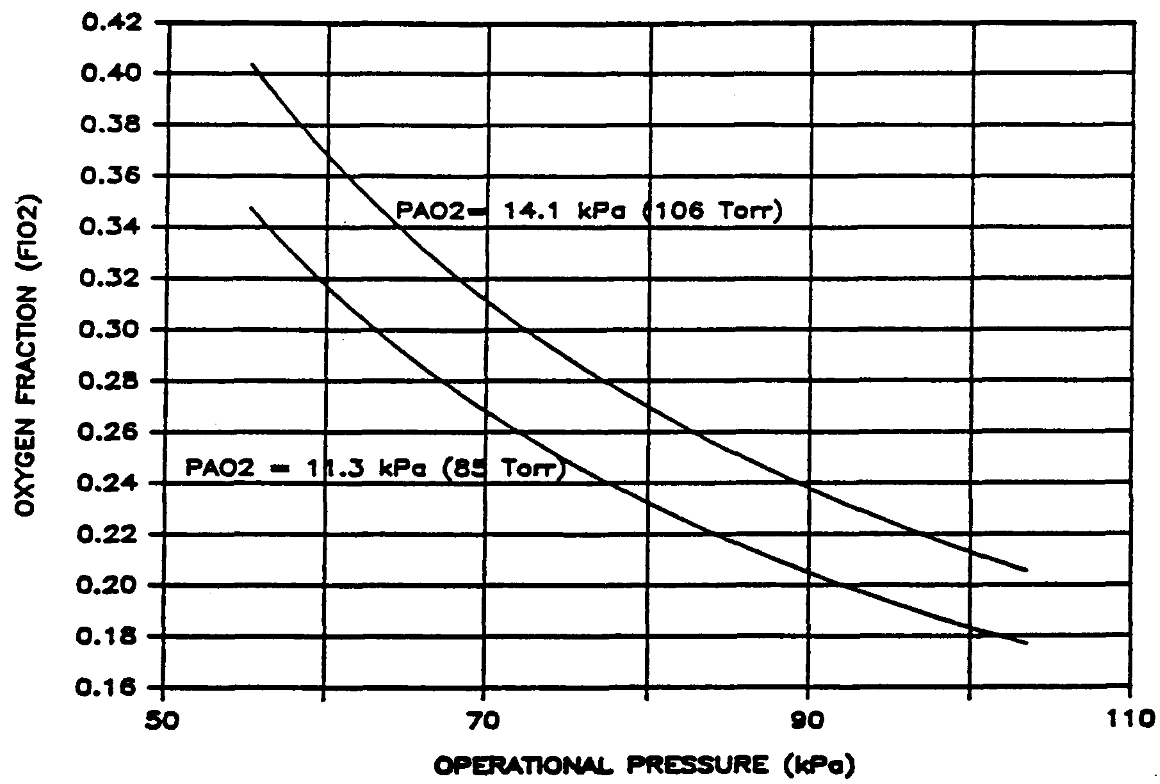
From Roth, (1968)

Table 3.2.4-1 Oxygen Cost of Various Activities on Earth

Activity	Oxygen Consumption liters/min	Equivalent Heat Production (kcal/min)
Asleep		
Sleeping, men over 40	0.22	77 (1.1)
Sleeping, men aged 30-40	0.24	84 (1.2)
Sleeping, men aged 20-30	0.24	84 (1.2)
Sleeping, men aged 15-20	0.25	91 (1.3)
Resting		
Lying fully relaxed	0.24	84 (1.2)
Lying awake, after meal	0.28	98 (1.4)
Very light activity		
Writing	0.36	126 (1.8)
Typing	0.46	161 (2.3)
Standing, relaxed	0.36	126 (1.8)
Drafting	0.38	133 (1.9)
Light activity		
Playing musical instruments	0.58	202 (2.9)
Scrubbing	0.94	328 (4.7)
Slow walking	0.76	265 (3.8)
Moderate Activity		
Rowing for pleasure	1.00	349 (5.0)
Cycling rapidly	1.38	482 (6.9)
Chopping wood	1.24	433 (6.2)
Baseball pitching	1.30	454 (6.5)
Table tennis	1.16	405 (5.8)
Tennis	1.26	440 (6.3)
Heavy activity		
Cycling at 10 mph, heavy bicycle	1.78	621 (8.9)
Shoveling sand	1.54	537 (7.7)
Digging	1.78	621 (8.9)
Playing soccer	1.66	580 (8.3)
Climbing stairs at 116 steps/min	1.96	684 (9.8)
Very heavy activity		
Cyclying at 13.2 mph	2.00	698 (10.0)
Fencing	2.10	732 (10.5)
Playing basketball	2.28	796 (11.4)
Climbing stairs	2.40	838 (12.0)
Extreme activity		
Wrestling	2.60	907 (13.0)
Harvard Step Test	3.22	1124 (16.1)
Mechanical Tasks		
Medium assembly work	0.58	202 (2.9)
Welding	0.60	209 (3.0)
Sheet metal work	0.62	216 (3.1)
Machining	0.66	230 (3.3)
Punching	0.70	244 (3.5)
Machine fitting	0.90	314 (4.5)
Heavy assembly work - noncontinuous	1.02	356 (5.1)

From Bioastronautics Data Book, 1973

Figure 3.2.4-3 Oxygen Fraction as a Function of Operational Pressure



The summary of data on CO_2 levels is as follows:

- o CO_2 production
  - 50 liters/hour (average) produced at 290 watts (250 kcal/hr) metabolic rate (200 cc/kcal)
  - 850 cc of CO_2 produced per liter of oxygen consumed

- o CO_2 partial pressure
  - Must be maintained below 1.0 kPa (.15 psia, 7.6 torr) for the metabolic rates of this scenario
  - Alarm for partial pressures above 1.3 kPa (.19 psia, 10 torr)
  - Terminate EVA for partial pressures above 3.1 kPa (.45 psia, 23 torr)

3.2.5 Thermal Storage of Body Heat

Standard heat transfer texts (Kreith, 1976 and Lienhard, 1981) define three modes of heat transfer:

1. Conduction, a process by which heat flows between regions or materials in direct physical contact;

2. Convection, a process of energy transfer involving heat conduction into a fluid, energy storage therein and mixing motion;

3. Radiation, heat transfer by electromagnetic radiation, occurring when bodies are separated.

A fourth "mode," recognized in physiology, which operates in cooperation with convection is evaporation, i.e., the energy absorbing change of phase of water. These modes can all be quantified, but the number of physical and geometric parameters that must be specified is large. In general, all

modes of heat transfer occur in proportion to a cross-sectional area (the area available for heat transfer). Conductive and convective heat fluxes occur in direct proportion to temperature gradient, and radiative flux is proportional to the fourth power of the (absolute) temperature difference. Of course, convection in space must be from a type of forced-air cooling.

The limits to crew performance may be defined in terms of the maximum allowable internal temperature, which is given as 39° C (102° F) for a resting or lightly working person (and 40° C [104° F] during exertion), or in terms of the maximum allowable heat storage, which is given as 1.5 kcal/kg of body weight (or 75 kcal/m^2 of body surface) (Grumman, 1985) and as 4.2×10^5 joules or 100 kcal (Waligora, 1979). The Grumman report (1985) and Marton, et al. (1971), both agree on the use of 0.83 as the average specific heat of human tissue, but differ in the description of heat storage. Marton (1971) offers formulae for terms in a heat balance <u>rate</u> equation, and so the heat storage term is made proportional to the time rate of change of temperature. Waligora (1979) and Marton (1971) consider the overall quantity of what one might call "excess" thermal energy stored in a human body. It is to this overall quantity that the numbers given above as "maximum allowable" pertain. With regard to the prediction of thermal limitation due to storage, Waligora points out that the approach is accurate when the limitation to heat transfer is the removal of heat. When heat storage is due to the failure of the thermoregulatory system, individual variations will make predictions less accurate. The implication of this fact is that, in the situation of a person working hard in a hot, dry and, "windy" environment, thermal storage of body heat may not be predictable on the basis of heat transfer theory alone. Thus, if a high ambient temperature in an EVA system becomes a possibility,

then individual testing of the crew in comparable laboratory conditions will be needed. Some dietary countermeasurements to heat tolerance, such as various electrolytes and vitamin C, might be of use.

The summary requirements for thermal storage of body heat are:

- o Established core temperature limits: 37° ± 1° C (98.6° ± 1.8° F)

- o Core heat storage (average)
  - ± 3.16×10^5 joules (300 Btu or 76.5 kcal) maximum
  - 6280 joules/kg (1.5 kcal/kg) of body weight
  - 3.16×10^5 joules/sq.m. (75 kcal/square meter) of body surface area
- o Metabolic heat removal
  - Utilize water cooling system

- o Maximum allowable heat storage
  - 1.13×10^5 joules/kg (2.7 kcal/kg or 4.9 Btu/lb) of body weight
  - 5.65×10^5 joules/sq.m. (135 kcal/square meter or 49.9 Btu/square foot) of body surface area

3.2.6 EVA Personal Hygiene

The established crew personal hygiene activities in preparation for EVA that have been demonstrated for EVA in LEO are also applicable to Advanced EVA in GEO. However, there is no clear requirement for full shower facilities in the MOTV due to the short mission duration. The use of sponges and skin wipes is appropriate. Attention should be given to deodorization as well as to the provision for a supply of pleasant aromas.

The MISTC must be designed for ease of cleaning and drying. Design efforts must be made to minimize the entrapment of dirt, cleaning solutions, biocides, and body fluids within crevices of the MISTC. All materials used in the MISTC should be selected such that they do not serve as major growth media for bacteria or fungi. Any lubricants required to be used with the MISTC should be designed to be applied under microgravity conditions and should meet all toxicity requirements.

Cleaning and disinfecting procedures for all materials in contact with a crewmember should be thorough, effective and simple to conduct. The use of large swabs which are saturated with cleaners and bactericides is appropriate. Drying is best effected by the use of forced air. Techniques should be developed for automated drying of the MISTC that allow each enclosure to be cleaned and dried within the time allowed between EVA episodes.

Given the relatively short times between the extended EVA of each crewmember, the use of salves or ointments may be important for crewmember comfort when abrasions have occurred. The types of activities in the scenario and the relatively loose-fitting suit could cause a crewmember to abrade his or her skin in unpredictable places. The use of a salve or ointment may be an important palliative (and lubricant) to relieve on-going skin irritation at pressure points.

During EVA, the "hands-in" capability afforded by the MISTC will permit the crewmember to clear nasal mucous by blowing his or her nose. Provisions for containing waste tissue should be provided.

Personal hygiene associated with waste management, particularly defecation and vomitus accidents, concerns

loose waste that may have escaped the primary control system. Provisions to wipe up these wastes should be provided. A cleansing and toweling mitten has been suggested for wiping and absorbing spills. This would permit the crewmember to turn the mitt inside out to contain wastes and odors.

Toweling materials should also be provided to absorb excess body perspiration - "wipe the brow" - if this should occur during strenuous activity.

The MISTC requirements to support personal hygiene include:

- o A design to be easily cleaned with a large swab saturated with cleaners and bactericide.

- o A design to be self-lubricated or easily lubricated with lubricants designed for application under microgravity conditions.

- o A design to minimize entrapment of dirt, cleaning solution biocides, or body fluids in any part of the MISTC.

- o Provisions for forced-air-dry after each EVA, with complete drying accomplished between EVA excursions.

- o A design which contains no microbial or fungal growth media.

- o A cooling garment designed to be cleaned after each use or for disposability.

- o Design of any human wastes containers, also covered under waste management, to be cleaned and disinfected after each use or for disposability.

The general requirements for personal hygiene can be summarized as follows:

o Activities prior to EVA:
  - Remove any/all cosmetics, ointments, and creams, except those designed for use in the MISTC.
  - Perform grooming, hair removal, and nail clipping as necessary to prevent irritation.
  - "Go to the bathroom."
  - Sponge bathe (no firm requirement for a shower facility in the MOTV short mission scenario).
  - Apply urinary and fecal collection devices.
  - Apply menses absorbent or collection device, if necessary.

3.2.7 Waste Management/Containment System

EVA missions in GEO will require that human waste products be containerized. This applies to urine, feces, menses, and vomitus. In the experience of other EVA missions, it is clear that crewmembers are uncomfortable with cumbersome devices for waste management and containment. Waste products should be collected in a way that is as non-invasive as possible to the crewmember. While diaper-type devices have been used in previous missions, this generally is not well-accepted. Simple adhesive, nonallergenic plastic urinary and stool containers are options, even though they will be considered somewhat encumbering by the users. Optimally, the use of food products that are of a low residue nature and of low moisture content, such that stool and urine output would be diminished, would be quite helpful. If a particular mission were of a rapid onset to correct an unexplained or unexpected event in geosynchronous Earth orbit, then it may be necessary to utilize personnel who have not had the opportunity to limit the diet as recommended. However, waste management and containment

remain a necessity and various devices must be considered. It may be possible to treat the urine and stool within the EVA enclosure to render it both non-noxious and physiologically safe. The quantities to be contained have been derived based on historical guidelines developed at LEO, and are considered appropriate for GEO.

The general requirements for waste management and containment systems for use in GEO EVA are as follows:

- All devices for hygienic collection, containment, storage, and disposal must be designed for operation in the microgravity environment.

- All waste management and containment devices must be designed to operate as a system in the MISTC for the maximum duration of EVA.

- The containment system must prevent solid, liquid, or gaseous contamination of the MISTC.

- The containment system must be designed to prevent cross-contamination to other MISTC subsystems, such as drinking water or food, circulating air supply, and helmets and visors.

- The urine containment devices must accommodate both male and female usage. An internal storage capacity for 1000 cc is recommended.

- The fecal containment device should have an internal storage capacity for 500 cc of waste material.

- The vomitus containment device should have an internal storage capacity of 750 cc and should be made of a flexible, non-transparent material.

- The menses containment device should be designed for 100 cc capacity. The use of conventional absorbent and collection devices, such as tampons or sanitary napkins, should be considered.

3.2.8 Food/Water

Provisions for adequate food and water will be necessary within the confines of the MISTC. As noted in the waste management and containment subsection, moisture content and production of bulky residues by food should be minimal. In previous missions, crewmembers were both unhappy and uncomfortable with food and water stores that were neither palatable nor similar to those experienced on Earth. Weight and volume limitations in the suit will make it necessary to provide small quantities of high-energy foodstuff that will be matched calorically to the physiological load anticipated during EVA. Prior studies have shown that 1000 cc (40 oz) of water and 750 kcal (2975 Btu) of food might be required during each EVA excursion in the baseline scenario. Based on the anticipated energy expenditure and the duration of each EVA, and recognizing the satisfying nature of "recreational" snacks, it is recommended that up to 1500 kcal (5900 Btu) of food be provided in the MISTC.

The general requirements for providing food and water to the EVA crewmember are as follows:

- Select materials used to contain and dispense food and water in accordance with FDA requirements.

- For food, make provisions to provide a minimum of 750 kcal (2975 Btu) of food. Allowance for up to twice this amount of food would better match the energy expended in EVAs.

- The "hands-in" capability and the use of food bars or packets should be considered for food and rest breaks and the types of food provided.

- Operating procedures should encourage high calorie intake of a low residue diet prior to EVA.

- For water, make provisions to provide up to 1700 cc (56 oz) of drinking water in the MISTC and use drinking bags containing positive-activation valving.

- The bag should be designed for disposability or for easy cleaning with antiseptic agents.

- The EVA crewmember should have the capability to supplement electrolytes (potassium) as required and directed without inducing diarrhea or other unwanted side effects.

3.2.9 Biomedical Data Monitoring

The anticipated medical conditions associated with extravehicular activity will dictate biomedical data monitoring. The crewmember population generally finds that biomedical data monitoring with invasive or cutaneous devices is both undesirable and unaesthetic. However, because of the critical nature of the physiological exposure during EVA, it may be necessary to have at least minimal monitoring for the first missions in order to develop baseline physiological information.

The kinds of medical conditions anticipated are barotrauma, involving the middle ear, the sinuses, and the alimentary tract; evolved gas dysbarisms that will manifest themselves in decompression sickness, as well as skin disturbances; gas embolism which can result both in airlock and during EVA;

conditions resulting from inadequate environmental control; mechanical trauma; and oxygen toxicity. It would be desirable to monitor the pressure of the MISTC to determine whether significant pressure changes take place. Devices have been developed that will determine an increase of bubble formation in the vascular tree; since pressure changes can indicate some expectation for the development of evolved gas dysbarisms, a non-invasive bubble formation detector (perhaps using Doppler techniques) could be an excellent monitoring tool. The type of detector could play a role in the early detection of gas embolism.

The use of non-invasive biomedical monitoring tools for body temperature could be useful during EVA, especially during heavy workloads, which result in dehydration detected by a rise in body temperature.

For measurements of workload, it will probably be necessary to monitor electrocardiographic data for heart rate and changes in heart rhythm, as well as respiratory rate, using advanced non-invasive techniques. Initial impressions of the monitoring requirements suggest that continuous monitoring of one lead of ECG (such as M-V5) and arterial oxygenation by the use of a pulsar oximeter would be highly desirable. The use of specialized techniques for rapid application of sensors and the minimization of motion artifacts would be essential. Derivation of respiration rate might be accomplished from the ECG electrodes as input sensors.

The need for real-time monitoring and real-time response to biomedical changes is paramount. It will require either human- or computer-assisted and generated monitoring that will provide for predictable revisions to EVA activities in the event of physiologic changes based on monitored data. While the specific techniques for providing this feedback have not been clearly demonstrated at this time, it is

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anticipated that an avorhythmic technique using "yes" or "no" responses to generated information will provide the criteria for activity modification. The locations of the storage and display of the data and the person or persons responsible for acting on the data must be established during mission planning.

The unique mission requirements regarding for data monitoring at GEO include the real-time monitoring of instantaneous and cumulative ionizing radiation exposure and the real-time monitoring of instantaneous, broad-band, radio frequency electromagnetic radiation exposure.

The general biomedical data monitoring requirements to support operational EVA at GEO are summarized as follows:

- o The operational data requirements include those data necessary to assess the real-time physiological well-being of the EVA crewmember such as respiration rate, heart rate, and body temperature.

- o The displays for biomedical data should be locally monitored by the IVA crewmember in the MOTV and selectively self-monitored by each EVA crewmember.

- o The data monitoring system should be compatible with the Space Station data management system, with data being updated once per minute, at a minimum.

- o The indirect measures to be gathered are:
  - Non-ionizing radiation exposure
  - Ionizing radiation exposure
  - Thermal metabolism
  - Enclosure pressure
  - Oxygen partial pressure in MISTC
  - Carbon dioxide partial pressure in MISTC

- The direct measures required are a Lead II (or equivalent) electrocardiogram which is processed at the display site for heart rate, arrhythmia detection, and respiration.

3.2.10 Medical Care/Facilities

The scenario involving the use of an MOTV to transport crewmembers from Space Station to workstation in GEO presents some unique challenges for the provision of adequate emergency and routine medical care. It is assumed that the nearest accessible major medical facility exists on Space Station, along with ancillary equipment and supplies. Therefore, from a medical care standpoint, the MOTV should be modelled as a remote urgent care vehicle, similar to a mobile coronary care unit or advanced life support vehicle, but with more diversified capabilities. Some of the provisions currently under consideration for the Crew Emergency Rescue Vehicle (CERV) could also be considered for installation in the MOTV. Because of the high-risk nature of the GEO scenario, the medical facilities and equipment in the MOTV must have the capability to stabilize an ill or injured crewmember for transport back to Space Station for more definitive care. The medical training of the crew and the practicality of including expert medical equipment and its attendant mass, volume, energy, and training requirements, must be considered against the probability of crew survival in circumstances requiring the use of such equipment. Trade studies should be made based on the probability of survivable versus catastrophic failure modes and their effects on life support systems and pressurized crew enclosures.

The pressurization of the MISTC with an air mixture rather than a highly oxygen-enriched atmosphere precludes the likelihood of oxygen toxicity. However, toxicity could occur under contingency emergency situations where high

partial-pressures of oxygen might be breathed for prolonged periods of time. Additionally, the use of a high pressure "suit" (57.2 kPa or 8.3 psia) eliminates the pre-breathe requirement for nitrogen washout. The small difference in pressure between the MOTV and the MISTC reduces the probability of evolved gas embolism to a minimum under routine operations. However, the possibility of a rapid decompression of either the MOTV or the MISTC does exist. Therefore, the probability of bends should be considered in the event of a major system failure or disruption of the skin integrity of either vehicle.

It is assumed that a slow leak of the pressurized vehicles will be brought to the early attention of the crewmembers by an appropriate caution and warning system. In this scenario, the crewmembers will have adequate time to implement contingency procedures. If the leak is in the MISTC, a rapid return to the MOTV should be the primary risk-reduction procedure. If a slow leak is detected in the MOTV, two conditions are possible. In the first case, the MOTV will have adequate pressurization capability to maintain a "shirt-sleeve" environment for its return to LEO, even though cabin pressure would have to be lower than nominal. In this case, the crew could breathe 100% oxygen to accomplish washout during a planned, stepped decompression procedure. Lower cabin pressure would be maintained in order to decrease the leak rate and conserve oxygen. In the second case, the MOTV will not be able to sustain the crew in a "shirt-sleeve" environment for the entire return trip to LEO and the leak rate will be high enough to preclude maintenance of acceptable pressures for the entire return. In this case, an emergency, "get-me-down" capability will be required. This could be accomplished by donning an emergency capstan pressure suit and breathing 100% oxygen under pressure. Emergency oxygen systems with pressure-demand regulators will be necessary.

Intermediate schedules of cabin, suit and breathing pressures should be developed to accommodate circumstances involving minimal cabin leaks up to maximum survivable leak rates. Such schedules would be followed by the crew, and would be dictated by the capability of the MOTV to sustain a given pressure during repairs in preparation for return to LEO.

In the event of a rapid decompression due to a major system failure, or a major disruption in the skin integrity of the MOTV or MISTC, mitigation must be carefully evaluated. In the MISTC, a rapid decompression could be catastrophic and fatal, regardless of the availability of a treatment facility onboard the MOTV. An emergency 100% oxygen, positive-pressure breathing mask would be effective initially; but if the MISTC decompressed to vacuum, the crewmember would have little time to return to the MOTV. It would be difficult for him or her to don a pressure suit within the MISTC, even if one could be provided. A rapid decompression of the MOTV is more likely to be survivable, due to artifacts being drawn into the rupture and partially sealing the leak. Again, positive pressure breathing with 100% oxygen would be an initial procedure. If the safehaven were not damaged, a separate pressurization system would allow the crew to enter safehaven and don pressure suits for the return mission.

Since, in this worst-case scenario, one or more crewmembers may be exposed to near vacuum for a significant time without pressure protection, dysbarism and subsequent gas embolization become a major probable risk. A hyperbaric capability could help minimize central nervous system (CNS) damage in the event of embolization. The MISTC could serve as such a facility if it were provided with adequate pressurization.

Trade studies for the requirement of a hyperbaric facility with a pressurization greater than 2.8 ATA should take the above contingency scenarios into consideration as the worst-cases. The capability must be provided to treat barotrauma and dysbarism, and to help prevent serious CNS problems in the cases cited.

Space motion sickness and its symptoms of headache, nausea and malaise usually occur early in the weightless environment. The MOTV crewmembers will have already been "seasoned" to the weightless environment aboard Space Station, and, therefore, will be at minimal risk for a recurrence of symptoms to any significant degree. However, the syndrome has recurred in crewmembers on long duration missions, and, consequently, must be considered.

The toxic hazard risk for this mission scenario is substantial due to potential exposure to hypergolic fuels and other toxins aboard the satellites to be serviced. Protocols for dealing with inhalation exposures resulting from possible life support system contamination and surface exposure decontamination should be clearly delineated for each of the anticipated hazards. These will be very similar to the protocol procedures for Space Station inhabitants, so no new technical data are anticipated.

Mechanical trauma within the MOTV and/or the MISTC should be considered as a possible occurrence. The severity of the trauma could range from minor cuts and abrasions to broken limbs and puncture wounds. Emergency supplies such as splints, suture, and antiseptic ointments, as well as instructions for a crew trained in their use, must be available on the MOTV.

Electric shock should also be considered as a remote risk. Injury could occur from burns, cardiac dysrhythmias

(including ventricular fibrillation) and mechanical injury due to recoil. This contingency alone warrants the presence of a cardiac monitor and defibrillator. Defibrillation would have to be instituted as soon as the dysrhythmia is recognized. It would be unacceptable medical practice to rely on mechanical external cardiac compression alone for transport back to Space Station.

Although the crewmembers' immune systems could be compromised from a sustained stay in the weightless environment, infections of crewmembers in the GEO scenario will probably be limited to those which were already incubating while aboard Space Station. It is assumed that infectious disease will be well-controlled on Space Station and that resident organisms will have been identified. The additional stress of the GEO mission may, however, cause subclinical diseases to become manifest. Antibiotic therapy must be available, by both oral and intramuscular routes, for the most common clinical infections seen on Space Station.

Beyond the Van Allen belts, which afford a protective radiation shield for LEO, the GEO scenario presents a greater risk of radiation sickness and/or a life-threatening radiation overdose. If it is assumed that the MOTV renders radiation protection against constant intergalactic radiation equivalent to an exposure rate no greater than the overall radiation exposure on Space Station, then the greatest risk at GEO will be unpredicted solar flare activity. It is not practical for the MISTC to afford the same radiation protection as the MOTV. As a result, redundant and precise monitoring of the crewmember in the MISTC is necessary. This should be accomplished with personally-worn monitors. Each MISTC crewmember's dose can then be added to his or her career dose by ground personnel. On the MOTV, monitors should be strategically located

throughout the vehicle for general mission dose detection. This dose should be added to the career total for all three crewmembers. In the event of a highly radioactive solar flare, portable shelters and the safehaven in the MOTV should be used for protection. Further consideration should be given to using some of the new, experimental drugs that promote the regeneration of bone marrow after destruction by high doses of radiation. Such developments, generally in the field of oncology, should be studied for possible utilization in this environment.

A concern, based on limited experimental evidence, gathered from young, healthy mountain climers at altitudes of 3,000-4,500 meters (9,842-14,764 ft) has recently been expressed for the development of hypercoagulability and thrombophlebitis. "There is no eveidence that anoxia alone causes thrombophlebitis, but other predisposing factors of mountain travel - dehydration, polycythemia, hypothermia, obstructive clothing, cramped quarters, and forced inactivity - may be incriminated." (Cucinell and Pitts, 1987). If this concern proves valid, then it should be assumed that the GEO EVA crewmembers will already be taking appropriate anti-coagulant countermeasures according to standard medical protocol.

Blood volume shifts and changes in plasma electrolyte concentration have been demonstrated to be adaptive mechanisms to microgravity. The added workload and metabolic load of two 10-hour EVAs on successive days may cause temporarily imbalanced electrolyte values. A non-invasive method of monitoring electrolytes and imbalances will probably be required. Dietary supplementations of possible critical electrolyte losses may also need to be part of the EVA protocol. This potential problem area can best be evaluated by a detailed analysis of the MISTC design and its thermal and ergonomic characteristics.

Other medical conditions, namely those treated by first aid such as minor burns and abrasions, are likely to occur and must be treated appropriately. Any medical problems not deemed to be definitively treatable in MOTV should be assessed for their severity and for the possible termination of the mission. Under these circumstances, the crewmember's condition should be stabilized, if possible, and the vehicle returned to Space Station. The prevention of shock should be a major goal in stabilization. Therefore, fluid and electrolyte replacement, maintenance of circulation, and ventilation are paramount considerations and should be reflected in the equipment and supplies stowed on the MOTV.

Based on previous discussions, the facilities, equipment and supplies required for the MOTV should include the following:

1. Portable radiation protective shelter,
2. Hyperbaric treatment capability up to 2.8 ATA,
3. Safehaven,
4. Mechanical external cardiac massage unit,
5. Pulmonary ventilator and respirator,
6. 100% oxygen supply with oral and nasal mask,
7. Cardiac monitor, defibrillator, and external pacemaker and
8. IV fluid administration system.

Various examination and treatment kits will also be required which are similar in content to the "High Technology Physician's Black Bag" and medical kits already developed by NASA and used in the past. These instruments will be needed to make and confirm diagnoses and to monitor the progress of a disabled crewmember.

In addition to these general medical requirements, certain aerospace medical life support capabilities should be

considered. These include:

- Positive pressure 100% oxygen from a demand regulator for the MOTV and MISTC emergency rapid decompression scenario. A mask should be considered as initial countermeasure.

- An emergency pressure suit and helmet with an integral positive-pressure and counter-pressure jerkin for a "get-me-down" capability. Safehaven of the MOTV could provide the temporary pressurized environment for donning such a pressure suit.

The "arms-in" capability of the MISTC will allow the crewmember to administer his or her own oral or injectable drugs as required. These could be provided in emergency kit form with the MISTC. The use of such procedures and drugs should be under the supervision of ground- or Space Station-based medical personnel. GEO crewmembers should be provided with training in advanced life support techniques and procedures equivalent, at a minimum, to the "paramedic" level. Instruction manuals and training for their use should be provided to GEO crewmembers. These manuals can be used to clarify procedures, maintain checklists, and instruct crewmembers in diagnosis and treatment in the event of radio communication failure.

The general requirements for medical care/facilities can be summarized as follows:

- All major medical care facilities to be located at Space Station, except for those emergency facilities required to stabilize a crewmember for transit.

- Possible medical problems:
  - Barotrauma
  - Evolved gas dysbarism
  - Gas embolism
  - Space sickness (nausea and headache)
  - Exposure to toxic substances
  - Mechanical trauma
  - Infection
  - Electric shock
  - Radiation sickness
  - Thrombophlebitis
  - Burns
  - Hypoxia or oxygen toxicity
  - Blood volume and electrolyte shifts
  - Thermal heat exhaustion or frostbite
  - Occular burns
  - Skin abrasions

- Facilities:
  - Portable radiation shelter
  - Safehaven
  - Hyperbaric treatment (up to 2.8 ATA)

- Medical equipment:
  - Mechanical cardiac massage unit
  - Pulmonary ventilator and respirator
  - 100% oxygen supply with oral and nasal mask
  - Cardiac defibrillator and external pacemaker
  - IV fluid administration system

- Examination and treatment kits:
  - "Physician's Black Bag"
  - Trauma treatment kit

- o Medication for use during EVA:
  - Analgesics
  - Antiemetics
  - Tranquilizers
  - Stimulants

3.2.11 Perception Acuity for Visual Displays and Warnings

All visual displays and warnings will be displayed within the helmet and visor field-of-view of the full range of operations of the MISTC. The technology for a see-through, heads-up display (HUD) is well-defined. All images on an HUD should appear in focus when the crewmember is looking at a distant object. Generally, this means that the virtual image must be located at a viewing distance greater than 18 inches away from the eyes of the crewmember. The brightness and contrast of the display should be adjustable over a range by the crewmember.

The display should accommodate a combination of alphanumeric and graphic data as well as raster-scanned video. Discrete warning lamps should also be used where appropriate. The transmittance and reflectance of the see-through display should be optimized, and any exterior HUD system should be capable of being repositioned by the crewmember.

The general requirements for perception acuity for visual display and warnings at GEO EVA can be summarized as follows:

- o Vision for all crewmembers should be 20/20 or corrected to 20/20 with individually-fitted, zero-g eyeglasses, if necessary.

- o The HMDs should provide:
  - Multi-functional, alphanumeric display, and video information,
  - All caution and warning visual displays in association with audible tones, and
  - Adjustable brightness and contrast.

- o Auditory perception may be reduced by fan noise, breathing and communications inside the enclosure. Audio annunciators should be designed to account for this potential masking. This applies to Section 3.2.12, below, as well.

3.2.12 Audio Level, Quality, Range, and Warnings

There are no requirements identified that are unique to the GEO mission. The requirements derived from NASA documents and engineering standards for LEO and other EVA environments are deemed to be applicable to GEO.

The recommendation for the use of a non-noise-cancelling microphone is based upon an analysis of the MISTC enclosure. In moderate sized helmets, a pronounced high-sound-pressure area exists only directly in front of the mouth. Beyond this region, the sound-pressure level varies only a few dB at any location in the helmet. Therefore, placement of a non-noise-cancelling microphone is not critical. The higher frequencies are increasingly attenuated as the placement moves further away from the mouth. However, a noise-cancelling element must be located directly in front and near the mouth or else the acoustic near-field cannot be well distinguished from the far-field. The desired signal will be severely attenuated. In larger, non-anthropomorphic enclosures, the sound pressure distribution is closer to freespace and the near and far fields may be more easily sampled. Noise-cancelling microphones, therefore, may be

more effectively used. In this case their use is recommended only if the background noise is appreciable.

Many aspects of speech recognition technology development impact the severity of requirements for the acoustic environment, transducers, and transmission quality. Significant progress is being made in this technology; thus, it is desirable to delay preparing the detailed specifications until the extent of planned usage of speech recognition hardware can be determined. It is desirable that a syntax of voice commands and vocabulary be developed by identifying and eliminating sounds which aggravate recognition limitations, and utilizing sounds which are found to be effective.

The voice synthesis system should be sufficiently flexible to support such varied applications as in-suit caution and warning, schedule reminders, systems configuration and status annunciation, and system check-out and maintenance. Unlimited vocabulary systems with a self-contained text-to-speech algorithm should be considered.

The general requirements regarding audio level, quality, range, and warnings that apply to EVA are:

- o Microphones should be redundant and non-noise cancelling.

- o Headphones and speakers can be used, except during propulsion phase of MOTV operation.

- o Feedback: Effective passive and active measures should be incorporated to allow open microphone and speaker operation.

- o Audio level should be capable of being set and controllable by the EVA crewmember up to a maximum level of 75 dBa.

- o The voice bandwidth should accommodate a range of 300 Hz to 5000 Hz, digital transmission.

- o Audio warnings should be consistent with those employed for the same purposes on Space Station.

- o Warning tones should sound continuously until positive action is taken.

- o Warning tone frequency should be selected for minimal masking from background noise.

- o The audio quality should allow a maximum intensity of 100 dBa.

- o The signal-to-noise ratio should be 50 dBa or better with audio distortion of less than 5%.

- o Transmission time delay should be minimized and within 50 milliseconds of video to assure "lip synchronization."

- o System should provide "very good" voice quality.

3.2.13 Perception of Surrounding Environment

The surrounding visual environment in GEO will be significantly different than that in LEO. The light reflected from the Earth and its dominance of the visual field will be reduced. However, from a design standpoint, the requirements to transmit a perception of the environment to the crewmember in EVA are basically no different in GEO than they are in LEO.

Current suit technology in providing adequate vision (visors) and adequate sensory feedback to touch (gloves) should be adequate for this mission. However, in the event it becomes necessary to initiate an emergency rescue of an EVA crewmember, it may be necessary to provide some locational aids for pinpointing the crewmember. Spatial orientation under GEO conditions will be degraded. Some design consideration has been given to the incorporation of automatic ranging into a "smart" TV camera. It will be necessary to provide some equipment to assist the crewmembers in determining the location of and range to large objects or other crewmembers.

The general characteristics which will influence perception at GEO are:

o Reduced reflection of light from Earth and Moon as compared to LEO

o Star field more evident than in LEO

o Earth size reference will appear smaller than in LEO

o Degraded depth cues based on textural gradients, interpositions, and object brightness

o The optical characteristics of current helmets and visors have been adequate to support EVA. For GEO EVA, changes in helmets and visors should continue to:
  - Provide good visibility
  - Provide protection against solar radiation
  - Provide appropriate reflectivity to light and heat
  - Provide protection against micrometeoroids and space debris
  - Provide a movable visor for enhancement of visibility.

- o Artificial lighting may be required for the correct perception of certain EVA tasks, and this light should illuminate selected areas from a minimum to 215 Lux (20 foot candles) to a maximum level of 2,150 Lux (200 foot candles).

3.2.14 Toxicity

The composition of chemical substances in the atmosphere of the MISTC must be analyzed based on information about off-gassing of materials and the organic volatiles that can be identified. Also, air contamination results from the metabolic waste products of the human in the MISTC - his or her expired air, perspiration, urine, feces, and flatus. It is obvious that potentially significant quantities of several hundred contaminants can be identified.

Any chemical capable of a chemical reaction in a body is a potentially harmful contaminant and could have an adverse physiological effect at some concentration on the human in the MISTC. The dose-response, i.e., toxic effects versus intensity and duration of exposures, relationships must be identified. The MISTC air contaminants can then be classified simplistically as asphyxiants, irritants, or toxicants.

Maximum allowable limits for potentially toxic materials must be related to the effects that release of all or portions of those materials might have on the crewmember in the enclosure. The effects of chemicals are likely to be modified by the physiological process of adaptation to the environmental conditions to which the wearer is exposed. For example, the contribution of skin absorption to total body dose is becoming a greater concern to toxicologists. Although it was once thought that the skin is a reasonably impermeable barrier, more recent studies have shown that a

variety of occupational exposures to chemicals are enhanced by dermal absorption (McDougal, et al., 1985). Physiologically-based toxicokinetic models are being used more frequently to predict what will happen when exogenous chemicals are introduced into living organisms. These models utilize commonly known physiological parameters, such as perfusion of organs with blood, to seek rate limiting steps in the absorption, distribution, and elimination of chemicals.

One of the well-known mechanisms of adaptation to thermal stress, either hot or cold, is redistribution of a portion of the blood flow from the body core to periphery to enhance heat loss from the body or, conversely, from the periphery to the core in order to minimize heat loss. With what is apparently a more significant contribution of dermal absorption than originally considered, the potential for peripheral blood flow to be the rate-limiting process must be considered, rather than just the rate of diffusion or other transport across the dermal barrier. The information required to utilize these models is not difficult to obtain and consists of factors such as aqueous solubility, distribution of cardiac output under a given set of conditions, and diffusion constants.

The maximum allowable limit for potentially toxic materials must, then, be related to the toxicity of those materials in the context of the physiological status of the individual wearing the suit. However, it must also be evaluated in the context of the criticality of the function, which could be altered by the effect of the toxicant. In industrial exposures, if the effects of the chemical can be mitigated by simply leaving the scene or by some other simple procedure, then such procedures are often initiated. In a closed environment, such as a nuclear submarine or space craft enclosure, a change in procedures is often not an

option, and the more conservative approach of utilizing larger safety factors must be employed. In the case of extravehicular activity, mitigative procedures are even more difficult; thus, the temptation is to invoke even larger safety factors. At some time, the ever-increasing attempt to err on the side of safety through the use of larger safety factors will make the allowable concentrations so small that they are practically unattainable. When the criticality of EVA tasks is viewed from this background, it makes the use of any new technology capable of more accurately predicting or inferring untoward effects from exogenous chemicals more attractive.

It is not anticipated that new or esoteric toxicologic problems will be encountered in this type of EVA at GEO. However, it is important that the following steps be taken:

- o Apply the most appropriate and innovative toxicologic technology to insure that existing limits are not unrealistically restrictive, and that any new limit selected for new materials is appropriate for the proposed usage of material.

- o Utilize the tools provided by physiologically-based toxicokinetic models to assess the potential for interaction between off-gassing and other chemicals and the altered physiological state in which the crewmember is likely to be operating.

- o Use only acceptable, "non-toxic" materials in accordance with approved lists and procedures (see NASA-STD-NHB-60601B).

- o Recognize that exposures will be to complex mixtures of potentially toxic materials. Toxicologic technology has developed to the point that it is much more capable of dealing with multiple (< 10) components of complex mixtures, both from an analytical and physiological effect reference.

3.2.15 Radiation Tolerance

Ionizing Radiation: The magnitude of a radiation hazard in space is dependent upon the kind of long-term mission to be undertaken. Both the quantity and quality of the radiation encountered will vary, and, consequently, the radiation's biological effectiveness as well. The greatest threat to life would probably result from the emission of high-energy particles during a solar flare. A great deal of information has been generated over the last 30-40 years on the biological effects of exposure to ionizing radiation and the relative biological effectiveness (RBE) of the various types of ionizing radiation. Biological effects that are of the most concern and therefore have been studied extensively are life-shortening effects, mutagenesis, and carcinogenesis. The information generated has been used by the National Council on Radiation Protection and Measurements (NCRP) to establish "safe" exposure limits for various occupations. It would appear that the prudent use of shielding and positioning of space vehicles can limit a human's exposure to radiation in space to the exposure limits set by the NCRP.

One biological effect that may not have been adequately addressed is the influence of relatively low level, chronic exposure on the immune system beyond the effects on blood forming organs (BFO). Blood cells, during circulation through the skin, may receive a higher dose of radiation than predicted for BFO. A blood cell of particular interest is the suppressor T lymphocyte (STL). In animal studies,

STL appears to be sensitive to ionizing radiation. Depletion of the STL population may enhance the possibility of developing an auto-immune disease. This may be an area, along with the other biological effects of ionizing radiation, that demands further investigation.

Non-ionizing Radiation: Potential exposure to ultraviolet radiation (UV) is greater in space than on Earth due to the protective filtration of UV (wavelengths less than 320 nm) by the ozone layer. Protection, however, is easily afforded with any number of materials which, if necessary, will allow the transmission of visible light. Recommended permissible UV exposure limits were given in an Advanced EVA System Design Requirements Study prepared for NASA by Grumman Corporation (1985). These limits range from an energy density of 0.09 J/cm^2 at 200 nm, declining to an energy density of 0.003 J/cm^2 at wavelengths of 260 to 280 nm, and then rapidly increasing to 1.0 J/cm^2 at 310 nm. These limits are within the Threshold Limit Values (TLV) adopted by the National Institute for Occupational Safety and Health (NIOSH). The TLVs are below most known thresholds for UV-induced erythema and photokeratitis. A non-medical effect of UV that must be considered is degradation of materials used during EVA. These concerns appear to be adequately addressed in the Grumman study.

A detailed study of radiation tolerance and shielding is presented in the following sections and in Section 4.5. Radiation dose guidelines for crewmembers of Space Station are currently under study by the NCRP.

It is evident from the following data for a ten-hour EVA that the skin of the crewmember will be the most sensitive organ in the GEO scenario and will require the most design work in order to provide adequate protective shielding. Some difficult tradeoff studies will be required during the

design of the gloves, where maximum flexibility will be required, implying a thin cross-section. Skin shielding requirements dictate the equivalent of approximately 0.5 cm (0.2 in) aluminum over all areas of the skin. Providing this level of protection will require an innovative design program.

There are three distinct environmental phases of the GEO mission: (1) orbital transfer through intense portions of the trapped proton belts, (2) inside the MOTV at GEO station, encountering the penetrating solar energetic particles and galactic cosmic radiation, and (3) on EVA at GEO station where trapped electrons dominate the radiation environment. The major components of the radiation environment are briefly reviewed below.

3.2.15.1 Solar Energetic Particles

In association with solar flares, the sun emits streams of high-energy protons and heavy ions called solar energetic particles. Proton energies are typically in the range 1 MeV to 100 MeV. Occasionally, harder spectra are observed with proton energies in the 1 GeV range. Frequency and intensity distributions of solar protons have been discussed by King. The heavy-ion component of solar energetic particles has been measured during the 1973-1983 solar cycle and analyzed by Chenette and Dietrich.

Twelve ordinary proton (OR) events during the 1966-1972 period had a mean particle fluence of 6.5×10^8 proton cm^{-2} for $E > 10$ MeV and 6.0×10^6 protons cm^{-2} for $E > 100$ MeV (King). The anomalistically large (AL) event of August, 1972 had a fluence of 2.2×10^{10} protons cm^{-2} for $E > 10$ MeV and 5.5×10^8 protons cm^{-2} for $E > 100$ MeV. The integrated fluence of heavy ions during the flare of 24 September 1977 was 1.65×10^3 particles cm^{-2} for $E > 100$ MeV. The maximum

possible fluence of a solar particle event is unknown. Fluxes of solar energetic particles at GEO are essentially unattenuated by the geomagnetic field.

The intensity and frequency of solar particle events appear to be randomly distributed. Proton intensities may be described with a log-normal distribution (King) and frequencies with a Burrell distribution (Burrell). Apart from the "rule-of-thumb" that most large events occur during periods of greater sunspot activity, there is no method available for making exact predictions of energetic particle events years, or even months, in advance.

Short-term predictions of solar energetic particle activity, days or hours in advance, have been somewhat successful (Heckman). Weekly predictions of solar activity in Preliminary Report and Forecast of Solar Geophysical Data are issued by the Department of Commerce, Space Environment Services Center (SESC). Real-time alerts are issued by the SESC (NOAA) when solar particle fluxes exceed thresholds of 10 protons cm^{-2} s^{-1} sr^{-1} ($E > 10$ MeV) and 100 protons cm^{-2} s^{-1} sr^{-1} ($E > 100$ MeV). Alerts are also issued when solar proton events are expected or suspected.

3.2.15.2 Trapped Electrons

Geosynchronous orbits exist in the central region of the outer zone of trapped electrons. Mean flux for $E > 2$ MeV is 3×10^9 electrons cm^{-2} near local noon and 1×10^9 electrons cm^{-2} near local midnight (Stasssinopoulos, NSSDC). The electron flux may vary by several orders of magnitude over periods of one week or less as a result of geomagnetic substorms and solar activity. Electron fluxes and geomagnetic indices are monitored in real-time by the SESC.

3.2.15.3 Trapped Protons

Trapped proton fluxes for $E > 1$ MeV are negligible at GEO. During orbital transfers from LEO to GEO, several hours are spent in the heart of the trapped proton belts. Trapped proton fluxes exceed 10^5 protons $cm^{-2}\ s^{-1}$ for $E > 10$ MeV and 10^3 protons $cm^{-2}\ s^{-1}$ for $E > 100$ MeV between 1000 km and 10000 km (Vernov). A two-hour passage through this region leads to radiation exposures comparable to an ordinary solar flare.

3.2.15.4 Galactic Cosmic Radiation

Galactic cosmic radiation consists of relativistic protons, alpha particles, and heavy ions with mean energy per nucleon greater than 1 GeV. Galactic cosmic radiation originated outside the solar system. The relative distribution of cosmic ray components is 90% protons, 9% alpha particles, and 1% heavy ions (Adams).

Cosmic ray proton fluxes at sunspot minimum are 4.1 protons $cm^{-2}\ s^{-1}$ for $E > 100$ MeV and 2.3 protons $cm^{-2}\ s^{-1}$ for $E > 1$ GeV. At maximum solar activity, cosmic-ray proton fluxes are reduced to 1.6 protons $cm^{-2}\ s^{-1}$ for $E > 100$ MeV and 1.2 protons $cm^{-2}\ s^{-1}$ for $E > 1$ GeV. The cosmic-ray fluxes are not attenuated by the geomagnetic field in GEO.

3.2.15.5 Radiation Tolerance

- o Calculated Exposure in Geosynchronous Orbits
  - Figure 3.2.15-1
  - Figure 3.2.15-2
  - Figure 3.2.15-3

o LEO-GEO Transfer

Calculated Organ Doses:

Organ	Dose (Rem)
Skin	7.94
Lens of Eye	4.46
Red BFO	1.59

Dose is for one 5.25 hr. transfer - 400 km - GEO Vehicle is 0.3 in. (2.06 g/cm^2) Al spherical shell orbit for minimum dose, initial long = 180°. Maximum dose for initial long. = 270° (42% higher).

General Requirements:

o Crewmember Exposure Limits (also in Section 4.5.5)

- Ionizing Radiation

	BFOs[a] (5 cm)	Eye (0.3 cm)	Skin (0.001 cm)
30 days	25 rem	100 rem	150 rem
Annual	50 rem	200 rem	300 rem
Career	100-400 rem[b]	400 rem	600 rem

[a] Blood forming organs (bone marrow)
[b] 200 + 7.5 x (Age - 30) males
200 + 7.5 x (Age - 38) females

- Non-Ionizing Radiation
  - 5 mw/sq cm (300 MHz to 1500 MHz)
  - 7100 mw/sq.cm (Max allowable peak exposure)
  - See Table 3.2.15-1
- Ultraviolet Light - Figure 3.2.15-4
- Visible Light - Figure 3.2.15-5

Unique Mission Requirements:

o Provide shielding to reduce calculated exposure in GEO to allowable exposure limits, plus a safety margin.

- Provide shielding in MOTV to reduce exposure in LEO-GEO and GEO-LEO transfer to acceptable levels to permit mission length with safety margins.

Table 3.2.15-1 Radio Frequency Protection Guide (RFPG) and Intermittent Exposure Limits from American National Standards Institute (ANSI) Standard C95.1-1982

Radio Frequency Protection Guide (RFPG)

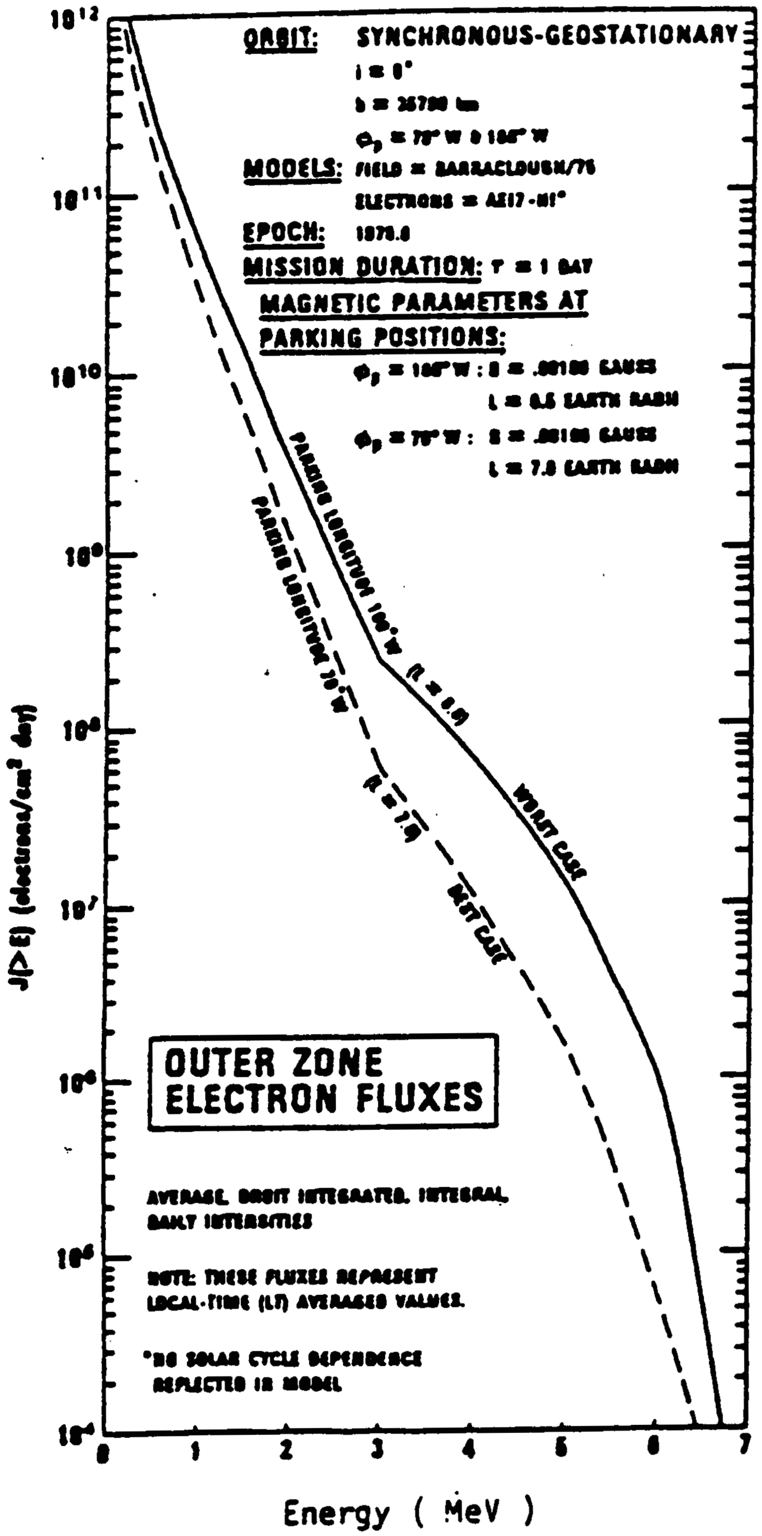
Frequency Range (MHz)	E^2 (V^2/m^2)	H^2 (A^2/m^2)	Power Density (mW/cm^{2H})
0.3-3	400,000	2.5	100
3-30	4,000 ($900/f^2$)	0.025 ($900/f^2$)	$900/f^2$
30-300	4,000	0.025	1.0
300-1,500	4,000 (1/3 CO)	0.025 (1/300)	1/300
1,500-100,000	20,000	0.125	5.0

Note: f is the frequency, in Megahertz (MHz)

Intermittent Exposure Limits

Exposure level (mW/cm^2)	Exposure time allowed	Time out of field
1.0	6 min.	---
1.5	4 min.	2 min.
2.0	3 min.	3 min.
3.0	2 min.	4 min.
5.0	1 min. 12 sec.	4 min. 48 sec.
10.0	36 sec.	5 min. 24 sec.

Figure 3.2.15-1 Integral Electron Spectra for Geostationary Orbit at Parking Longitudes of 160° (Worst-Case) and 70°W (Best-Case)



From Stassinopoulos, 1980

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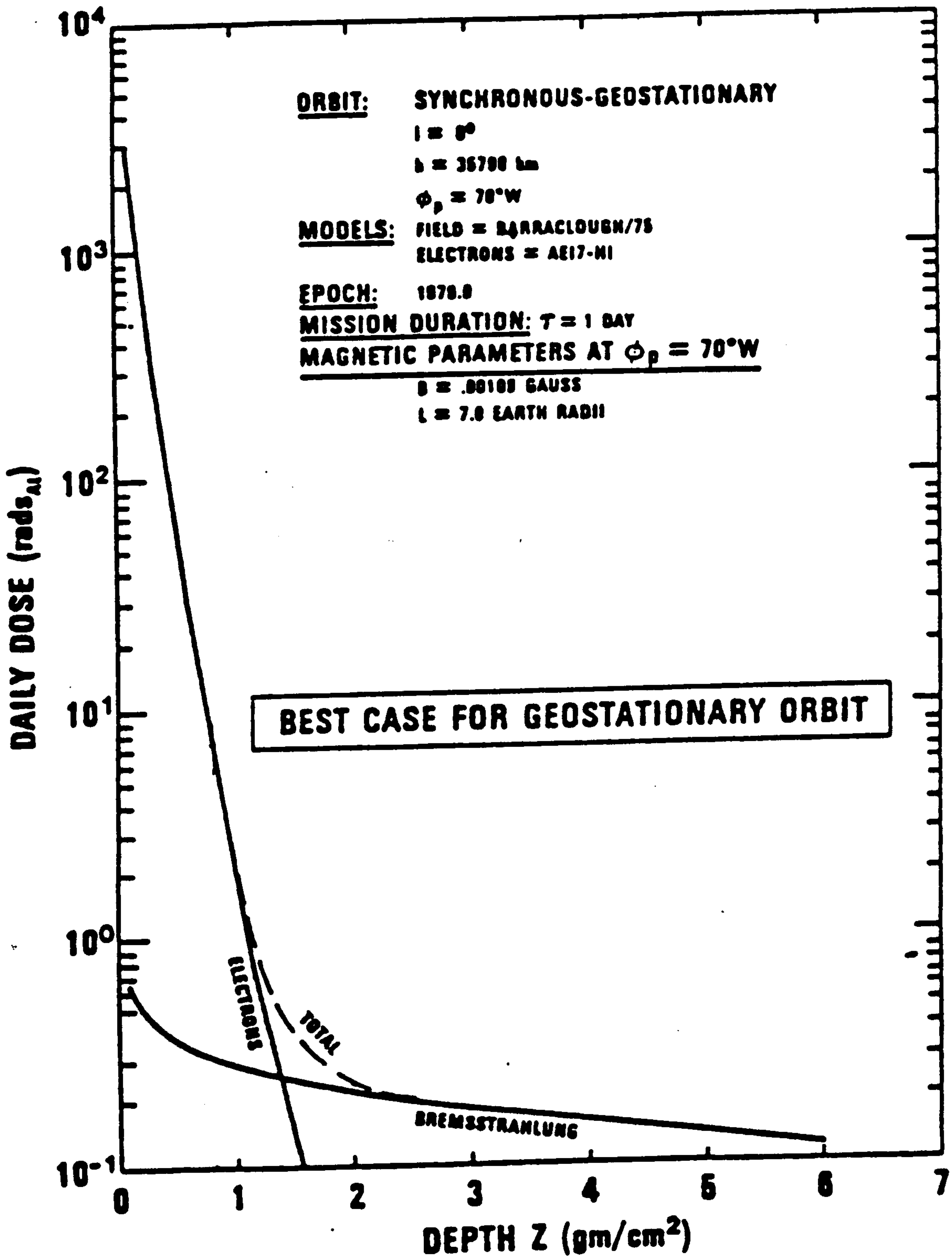
Figure 3.2.15-2 Daily Dose from Trapped Electrons Plus Bremsstrahlung in Geostationary Orbit at 70°W Parking Longitude (Best-Case)



From Stassinopoulos, 1980

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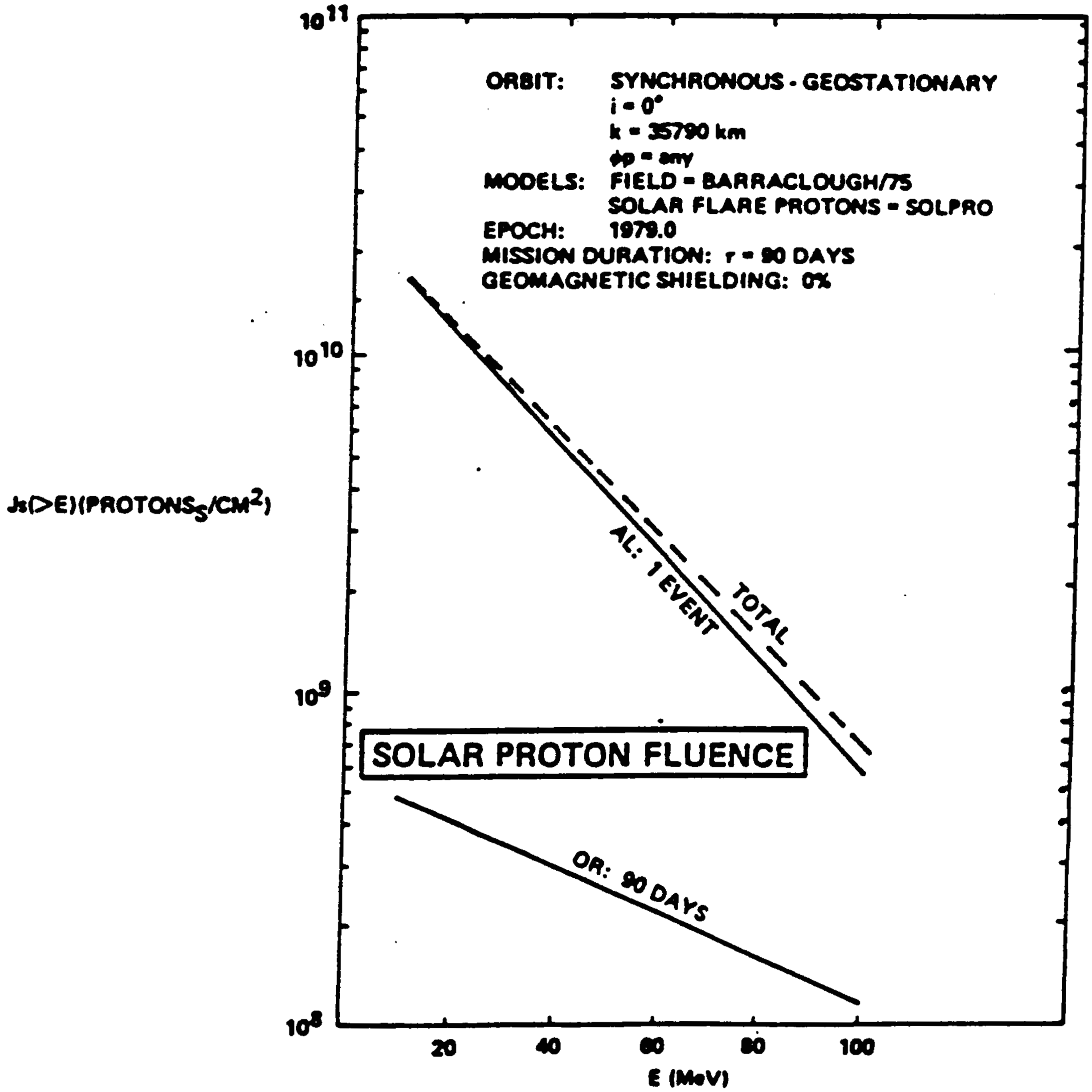
Figure 3.2.15-3 Solar Proton Integral Fluence Spectra in Geostationary Orbits



From Stassinopoulos, 1980

Figure 3.2.15-4 Ultraviolet Radiation Exposure Limits

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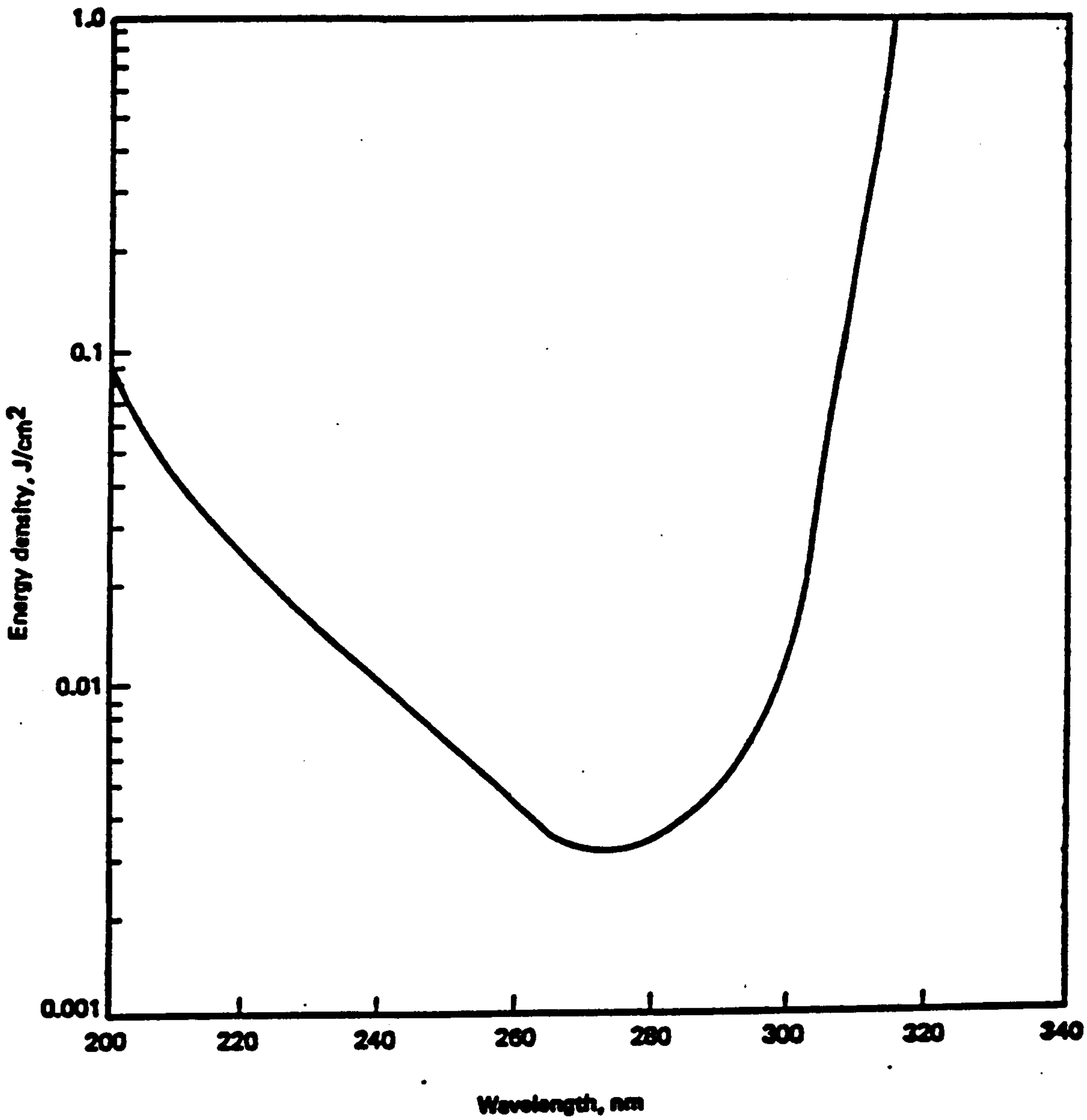


From Boeing, 1986, pg. 113

Figure 3.2.15-5 Maximum Permissable Exposure Limits for Visible Light

Maximum Permissable Exposure Values for Point Source Radiation Between 400-700 Nanometers (with 7 mm limiting aperture for $t = 10^4$ sec)

Wavelength (nm)	MPE (MJ/cm^2)
400-450	3.
451-500	6.
501-550	12.
551-600	35.
601-650	100
651-700	500

Note: For t 10 seconds, multiply the above MPEL by $.18(t)^{.75}$

Maximum Permissable Exposure Values for Extended Source Radiation Between 400-700 Nanometers (with 1 mm limiting aperture at cornea and time, $t = 10^4$ seconds)

Wavelength (nanometers)	MPE ($Joules/cm^2$-sr)
400-450	6
451-500	12
501-550	24
551-600	70
601-650	200
651-700	1,000

Note: (1) For t 10 seconds, multiply the above MPE values by $(t)^{3/4}(.18)$

(2) Source solid angle, in steradins (sr).

$= \text{Area}_{\text{source}} / (\text{Distance to source from eye})^2$

From Grumman, 1985

3.2.16 Micrometeoroid/Impact Requirements

The difficulty of meeting the requirement to protect the EVA crewmembers at GEO from impacts with micrometeoroids and space debris is a function of the probability of encountering such objects. Evaluating the probability requires the consideration of both trackable and non-trackable items. V.A. Chobotov (1982) has developed a model for predicting the collision hazard in the geosynchronous corridor for trackable and catalogued artifacts. The model is based upon the size of objects, the known orbital parameters, and time. Based upon the 1980 NORAD catalog of all trackable objects in geosynchronous orbit - some 200 of them - and anticipated orbital insertions, failures, and replacements, the projection is that some 850 artifacts will reside in the geosynchronous corridor in the 1987-90 period. These objects are satellites, shrouds, and explosion fragments on the order of 3-10 m in radius (10-30 ft). Objects and particles which are below the threshold of tracking systems are inferred from LEO experience and predicted to be "significantly greater than that which is cataloged" (Chobotov).

The highest density of LEO orbital artifacts is in the 500-1500 km range (approximately 10^{-8} objects/km^3). For the narrowest geosynchronous band (±0.2°, inclined within 0.06° and at geosynchronous altitude ±10 km), the tracked object density is also approximately 10^{-8} objects/km^3. This falls to slightly less than 10^{-9} objects/km^3 for objects inclined about 1° within a latitude band of ±5° at geosynchronous altitude. Within this distribution and density, Chobotov predicts the collision probability with a target radius of 6 m per 1000 days to be about 9.0×10^{-7}. This compares to $p = 3.0 \times 10^{-4}$ for a collision in 1000 days in the 800 to 1500 km altitude band, and 4.0×10^{-7} for a "typical" geosynchronous spacecraft.

The mean relative velocities of objects in LEO and GEO are greatly different, with the advantages being at GEO where relative velocities are on the order of 100-150 m/sec compared to 8-14 km/sec at 500 km altitude (Chobotov, 1983).

For large, trackable artifacts, the density distributions, mean relative velocities, and the resultant probability of impact impose less severe requirements at GEO than at LEO. Accordingly, if the LEO requirements are met, the GEO requirements fall within these impact/collision boundaries.

For smaller particles and micrometeoroids, the requirements for EVA at LEO are also more severe than at GEO. Figure 3.2.16-1 from the Advanced EVA Systems Studies for Space Station show the EVA suit hazard assessment for a 500km orbit inclined 60°.

Figure 3.2.16-1 EVA Suit Hazard Assessment* Orbit 500km/60°

DEBRIS			MICROMETEOROIDS				SUIT				COMBINED (DEBRIS-MICRO-METEOROID) NO-DAMAGE PROBABILITY (P_O)*
MASS (G)	DIA. (CM)	FLUX (#/CM²/YEAR	MASS (G)	DIA. (CM)	FLUX (#/CM²/YEAR	KINETIC ENERGY (ERGS)	ELEMENT	AREA (M²)	MAT'L	THICKNESS (CM)	
$3.3x10^{-3}$	$1.3x10^{-1}$	$9x10^{-4}$	$8.3x10^{-3}$	$1.5x10^{-1}$	$7x10^{-4}$	$1.88x10^{8}$	LOWER LEGS	.17	ALUM 6061-T6	.47	.999981
$3.3x10^{-3}$	$1.3x10^{-1}$	$9x10^{-4}$	$8.3x10^{-3}$	$1.5x10^{-1}$	$7x10^{-4}$	$1.88x10^{8}$	UPPER LEGS	.03	ALUM 6061-T6	.47	.999977
$3.3x10^{-3}$	$1.3x10^{-1}$	$9x10^{-4}$	$8.3x10^{-3}$	$1.5x10^{-1}$	$7x10^{-4}$	$1.88x10^{8}$	UPPER ARMS	.05	ALUM 6061-T6	.47	.999971
$4.4x10^{-5}$	$3.1x10^{-2}$	$5x10^{-2}$	$1.1x10^{-5}$	$3.5x10^{-2}$	$5x10^{-2}$	$2.22x10^{7}$	WAIST	.16	LAMINATE	.07	.991413
$4.4x10^{-5}$	$3.1x10^{-2}$	$5x10^{-2}$	$1.1x10^{-5}$	$3.5x10^{-2}$	$5x10^{-2}$	$2.22x10^{7}$	SHOULDERS	.08	LAMINATE	.07	.990394
$1.13x10^{-3}$	$9.1x10^{-2}$	$1.2x10^{-3}$	$2.8x10^{-4}$	$4.8x10^{-2}$	$2x10^{-2}$	$5.64x10^{8}$	SHOULDERS	.16	SS	.08	.985759
$1.13x10^{-3}$	$9.1x10^{-2}$	$1.2x10^{-3}$	$2.8x10^{-4}$	$4.8x10^{-2}$	$2x10^{-2}$	$5.64x10^{8}$	THIGHS	.38	SS	.08	.985631
$1.54x10^{-3}$	$1.0x10^{-1}$	$1.2x10^{-3}$	$3.8x10^{-4}$	$5.3x10^{-2}$	$2x10^{-2}$	$7.7x10^{8}$	HARD UPPER TORSO	.55	FIBERGLASS	.19	.985497
$2.3x10^{-5}$	$2.5x10^{-2}$	$8x10^{-2}$	$5.7x10^{-6}$	$4.5x10^{-2}$	$2x10^{-2}$	$1.1x10^{7}$	HELMET	.25	LEXAN	.19	.979116

*BASED ON 938 HRS EVA

R-0550-133TI

For meteoroid impact requirements, the NASA SP-8013 Meteoroid Environmental Model was employed, specifically, the total meteoroid flux-mass model was adapted for the cislunar environment. The average cumulative total meteoroid flux-mass model is the average sporadic plus the average stream model over time. At geosynchronous orbit, the total meteoroid flux must account for the defocusing effect of Earth (.635 times flux), yielding a quantity over time lower than those in LEO. Current EVA safety and impact protection requirements to support the crewmember at LEO should therefore be acceptable for the GEO micrometeoroid environment. This is confirmed in communications with JSC and industry experts (Kessler, Johnson).

4.0 EVA HARDWARE AND HARDWARE INTERFACE REQUIREMENTS

4.1 Design Loads, Operating Life, and Safety Factors

The GEO natural environment imposes additional requirements beyond those familiar to planners for LEO EVA tasks. GEO flights outside the protective magnetic fields will be vulnerable to both nominal and unpredictable high bursts of solar-ionizing radiation, which combined with the long transfer time from GEO to LEO, pose additional design and planning problems in specifying design loads, operating life, and safety factor parameters for GEO missions. Limited space for transport and stowage of EVA hardware used in GEO is a consideration which will influence design loads. The size and mass restrictions on MOTV will require the transport of only mission specific hardware, plus a small set of generalized and contingency EVA hardware, on each GEO mission. The size, mass, and stowage space restrictions of MOTV, combined with the operating life of EVA hardware used, will require that redundancies on EVA hardware be limited to EVA hardware critical to specific mission success. Other EVA hardware that might be useful on a particular GEO mission, but not critical to mission success, will not be redundant. Any EVA hardware with a mean-time-between-failure operating life greater than the planned mission length (15 days) should be classified as non-redundant EVA hardware and will be adequate for GEO flights.

The use of mission specific hardware will eliminate the need for a large standard GEO EVA hardware package carried on each GEO flight. Each GEO flight will have a mission specific EVA hardware package, plus the smaller standard hardware package. The MOTV will be outfitted for a particular mission during the planning stages of the mission on Space Station or on Earth.

Specific EVA hardware packages will be designed to be stowed on the MOTV in low mass fabric compartments or stowage bags for easy removal and outfitting. This will allow for most EVA hardware to be placed in a common space designed for stowage on the MOTV. In the case of a mission that requires hardware larger than the designated space, stowage provisions should be made for external EVA hardware stowage on MOTV. External stowage should be designed to protect EVA hardware from micrometeoroid, radiation, and thermal change damage.

4.2 EVA Tools

The existing EVA tool inventories developed for use in LEO will serve as a good generic base for selecting GEO tool kits. However, the more varied demands of the environment and the need to minimize EVA time at GEO will justify the development of a wider and more versatile range of both and hand tools and power tools.

One effect on tools created by the additional requirements for temperature control for GEO satellites will be the addition of tools to manage the removal, and addition, cutting and patching of Multi-Layer Insulation (MLI).

If MLI cutting is required for GEO EVA repair, a method for MLI debris and contamination management will be necessary.

Any fuel or fluid replenishment will require the use of fluid management systems and specialized fueling kits for systems which may not have been designed for EVA fueling. These will include protective shields or covers to contain any fuels or fluids at the resupply connector joints, and will also prevent contamination of the worksite and EVA crewmembers.

At GEO, there will be continuing problems with satellites not designed for EVA servicing and maintenance. Fastener removal, retention, replacement and special test, and check-out devices for specific satellites will pose design and planning challenges.

Because of mass and volume limitations placed on tool inventories at GEO, (Section 4.1), tools with multiple uses will be needed. This will lead to the expansion of tool approaches that will permit tool configuration and reconfiguration by the crewmember at the EVA workstation.

4.3 Restraints/Workstations

LEO EVA restraint/workstation technology including MFR and other RMS workstations will be widely applicable to GEO. There will likely be a greater requirement to plan for unprepared EVA work sites, that is, satellites not built with EVA in mind, and the need for portable test and diagnostic devices, including video, to increase EVA mission success.

One feature of the MISTC that permits restraint and reconfiguration at the worksite is the pair of manipulator arms attached to the lower portion of the enclosure. These can provide a means for attaching and stabilizing the crewmember at the workstation.

When the MISTC is supported at a worksite while attached to the MOTV RMS, these manipulator arms can also serve as holding and positioning aids for the crewmember.

In view of the fact that the current GEO satellite population was not designed to accommodate on-orbit servicing, the use of conventional foot restraints, which

require preparing the satellite with appropriate structures to hold them, is not thought to be a practical approach.

4.3.1 Crew Member Translation/Equipment Translation

Crewmember translation on GEO EVA should closely parallel the approaches used in LEO. One difference in GEO EVA will be the necessity for EVA personnel to be able to translate from an EVA worksite or workstation to a safehaven in the MOTV before damage can occur from solar energetic particle events. Protection from these solar flares will require EVA personnel to translate to the MOTV, egress from the EVA enclosure, and move into the safehaven. Consideration must be given for translating from the EVA worksite or workstation to the safehaven by the slowest translation methods, such as hand movement on tether lines, slide wires, or on spacecraft surface handholds. These translation time requirements will drive design criteria for modes of translation. Translation time factors should be based on the operational working distances between the worksite and the MOTV. If the GEO satellite is grappled by the MOTV, this will be a relatively short distance, on the order of meters. If, on the other hand, the GEO satellite and the MOTV are in a standoff condition, translation over longer distances will have to be factored. These greater distances are a function of specific mission requirements.

Different modes of translation could include the increased use of extenders and retractors or mechanical positioning and translation devices, such as the RMS, between the spacecraft and payloads or satellites being tended.

These devices would be preferable to an EEU-type device because of doff or egress time contraints. In the case of extender/retractor malfunctions, the physical structure of the devices would serve as a tether handhold or slide wire

from spacecraft to the payloads or satellites, which would be the slowest translation method and the basis for translation timelines and spacecraft-to-payload or satellite positioning criteria.

4.3.2 Worksite Interface Requirements

Ideally, all GEO EVA tools or hardware would interface with all spacecraft and satellites. However, this is not possible with spacecraft and satellites not designed for EVA.

Interface requirements for restraints and handholds, tethers, tools or hardware, and translation devices for spacecraft and satellites designed for EVA should correspond to EVA worksite/workstation requirements.

For spacecraft and satellites not designed for EVA, the interfaces between restraints and handholds, tethers, tools or hardware, and translation devices must be mission specific.

In addition to the worksite accommodations for workstation restraint, crew and portable equipment restraint, visual and physical access, lighting or shading, and work envelope, GEO EVA will likely require special mechanical and electrical interfaces to effect servicing and repair. Other possibilities include fluid loop servicing and a requirement for thermal, electrical or chemical insulation/isolation. Special equipment to control stored mechanical energy may also be needed.

EVA lighting should be redundant, portable, located outside the support craft, and should provide voice-activated pointing adjustment, particularly for lighting beyond the working envelope of the restrained EVA crewmember.

EVA video cameras should be miniature, mounted outside the visor, and provide for voice-activated functions - pan, tilt, zoom, focus, aperture, gray scale stretch, and automatic gain control (AGC) response (peak and average). A smart camera, currently being designed at NASA JSC, can provide range, range rate, pattern recognition, tracking input to pan, and tilt or propulsion autopilot;this technology issue should be investigated.

Voice activation of many functions may be highly desirable for a single EVA crewmember performing complex tasks. Control and positioning of lighting, video camera, tool configuration, and work or EVA positioning are among suitable candidates for consideration.

4.3.3 External Configuration

Standard requirements pertaining to handholds and handrails, tether attach points, foot restraint attach points, auxiliary hardware attach points, and special fixture mounts will be imposed on any manned spacecraft designed to accommodate and support EVA. However, to support EVA in GEO, spacecraft will be required to accommodate the wide variety of external hardware necessary to perform GEO EVA missions, particularly, on spacecraft and payloads not designed for EVA operations.

Because of EVA constraints imposed in requirements (Sections 4.1, 4.2, 4.11), the external configuration of EVA supportive spacecraft must accommodate a wide variety of possible EVA scenarios. These scenarios will include both soft and hard docking capture devices for spacecraft and satellites in stable orbit or out of control. Other external configuration capabilities of EVA spacecraft will include a means to secure the spacecraft or satellite after capture, a means to power up systems of disabled or

serviceable spacecraft and satellites for system analysis and check-out, and a means to reboost spacecraft and satellites.

Other considerations will be given to external tool storage and access and to worksite/workstation stowage and access. Proximity to EVA work areas would limit worksite and workstation setup and clean-up time.

The external configuration will accommodate the removal and translation of ORUs or modules with a wide range of masses and volumes.

4.3.4 Sharp Corner/Impact Requirements

Since current GEO satellites are not designed for EVA servicing, GEO EVA will likely require much greater diligence in precluding personal injury and/or equipment damage from sharp edges, rough, abrasive, hot, caustic or charged surfaces, and kinetic and stored mechanical energy. In past programs, EVA tasks planned for equipment already in orbit have not gone as planned because of imprecise knowledge of the configuration of the flight hardware. GEO EVA planning will require a conservative approach to avoid unanticipated hazards. The current standards in NASA STD 3000 and Sharp Edge Criteria for Shuttle Payloads, EM 84-2000, are viewed as a baseline even for the MISTC concept due to the fragility of the gloves.

4.4 EVA Rescue Equipment Requirements

GEO *EVA* rescue will rely largely on the equipment already available, such as redundant EEUs, safety tethers, and transfer lines. The addition of extender and retractor devices could improve rescue capability (Section 6.4). Other capabilities that would improve GEO EVA rescue

capability include the use of transponder devices on EVA crewmembers and onboard capability to locate and range on a free-drifting EVA crewmember. Equipment should also be provided to transfer a disabled EVA crewmember from a workstation restraint to the onboard airlock (2nd EVA assisting).

4.5 Radiation Shielding

The radiation environment in GEO has three separate sources, galactic cosmic radiation, solar particle events, and trapped particles (protons and electrons). Each source should be considered separately for its potential radiation hazards:

Galactic cosmic radiation consists of very high energy (about 1 GeV per nucleon) protons, alpha particles, and heavy ions. These particle fluxes are not attenuated by either Earth's atmosphere or Earth's magnetic field in the GEO scenario. A maximum dose rate of approximately 1 rem per week can be expected from this source. Three cm of aluminum shielding reduces the dose by approximately 50%. Conclusion: On the order of 0.5 rem will be absorbed from galactic cosmic radiation over the nominal 4-day GEO mission. Practical amounts of shielding cannot effectively reduce this dose.

Solar Energy Particle Events - In association with solar flares, the sun emits streams of high-energy protons. A representative energy is about 100 MeV. These events can be observed on the order of 1 hour before energetic particles reach the spacecraft. Absorbed doses to crewmembers from these events are highly variable. The flare of August, 1972 would have been lethal to Apollo crewmembers in transit to the Moon. A variety of flare dose studies have been performed. Letaw's study (1986) includes analyses of

primary protons and secondary particles, e.g., neutrons. He finds that crewmembers with 2 cm of aluminum shielding receive a dose of about 13 rem/hour for a flare the size of the August, 1972 flare. With 4 cm of shielding, the dose is about 5 rem/hour. With 7.5 cm of shielding, the dose is about 2 rem/hour. A conceivable "worst-case" flare may deliver 20 rem/hour. Conclusions: If proper detectors are available in the spacecraft, flares can be observed about 1 hour before there is radiation danger. This allows the crewmembers within the MOTV time to prepare a safehaven or "storm shelter." The design criteria for the safe haven must allow assembly or activation within 1 hour. Two classes of protection should be considered for radiation protection - one, "active," such as an electromagnetic shield and the other, "passive," such as a shielded storm shelter.

An active radiation protection device should be a superconducting electromagnet that envelops the MOTV in a magnetic field and deflects or captures incoming radiation. Posed as one of the future research issues in Appendix 2, radiation deflection is considered possible. The Univeristy of Alabama in Huntsville is currently working on approached to employ "high" temperature superconducting magnets as deflectors. Active shields must be appropriately oriented and distanced to avoid trapping and focusing incoming radiation at the MOTV through the magnetic polar cusps.

The other class of protection, a passive device that takes the form of a storm shelter, should protect the crewmembers with about 4 cm of aluminum. During an intense flare crewmembers would receive 40 rem during their emergency return to LEO. At LEO the dose rate is significantly lower because of the Earth's magnetic field. The total dose may not exceed annual limits for crewmembers. A storm shelter composed of 2 cm aluminum would allow the crewmembers to

survive the return trip to LEO. The crewmembers would have some signs of radiation sickness (nausea or vomiting, at least). It would be advisable to return them to Earth immediately for treatment.

Trapped Particles (Protons and Electrons) - During the trip from LEO to GEO, the crewmembers will pass through the radiation belts just as in the Apollo missions. Approximately 1 rad will be absorbed during this transit. In GEO, the trapped electron population and X-rays from their interactions in shielding will make a major contribution to crewmember radiation dose. The dose is more sensitive to shielding thickness and material than the galactic cosmic radiation dose. An analysis by Dr. Percival McCormack indicates that the radiation dose from the trapped electrons with 5 cm aluminum shielding is about 0.2 rem for the nominal 4-day mission, and about 0.1 rem with 13.5 cm of aluminum shielding.

In order to prepare an assessment of radiation hazards and shielding requirements on the GEO mission, estimates of dose versus depth in shielding materials must be made. Several shielding computations which are applicable to the present study have been performed in the past. This report utilizes currently available shielding computations. Computations of shielding requirements for the purposes of validating published results and improving deficiencies in our knowledge have not been attempted. The impact of shielding on doses from four components of the environment (also in Section 3.2.15) is reviewed below.

4.5.1 Solar Energetic Particles

According to the Burrell distribution as applied to the period 1966-1972, there is a 2% chance of a large OR event

and a 0.3% chance of an AL event occurring during the 4-day GEO mission.

Dose rate versus shielding depth relations have been computed by Letaw and Clearwater for the AL event of August, 1972 (see Figure 4.5.1-1). The computation includes the production of secondary particles from proton interactions and appropriate quality factors. This dose computation is representative of an AL event; however, it is conceivable that the actual dose from an AL event could be substantially greater than in August, 1972 (e.g., the worst-case dose rate shown in Figure 4.5.1-1).

It is estimated that the dose rate for a large OR event would be 50 to 100 times less than for an AL event.

Chenette and Dietrich computed linear energy transfer (LET) versus aluminum shielding depth relations for the heavy-ion rich solar energetic particle event of 24 September 1977 (Figure 4.5.1-2). Their results suggest that the LET spectrum is similar to the cosmic-ray LET spectrum. Consequently, the radiation dose from this event is simply proportional to the galactic cosmic ray dose for one day, which is 0.15 rem. It is estimated that the event-integrated dose (using one-half of the peak dose rate for one day) behind 100, 200 and 400 mils of aluminum shielding is 2.6 rem, 1.0 rem and 0.5 rem, respectively.

Figure 4.5.1-1 Computed Dose to Bone Marrow Versus Aluminum Shielding Thickness for Two AL Events

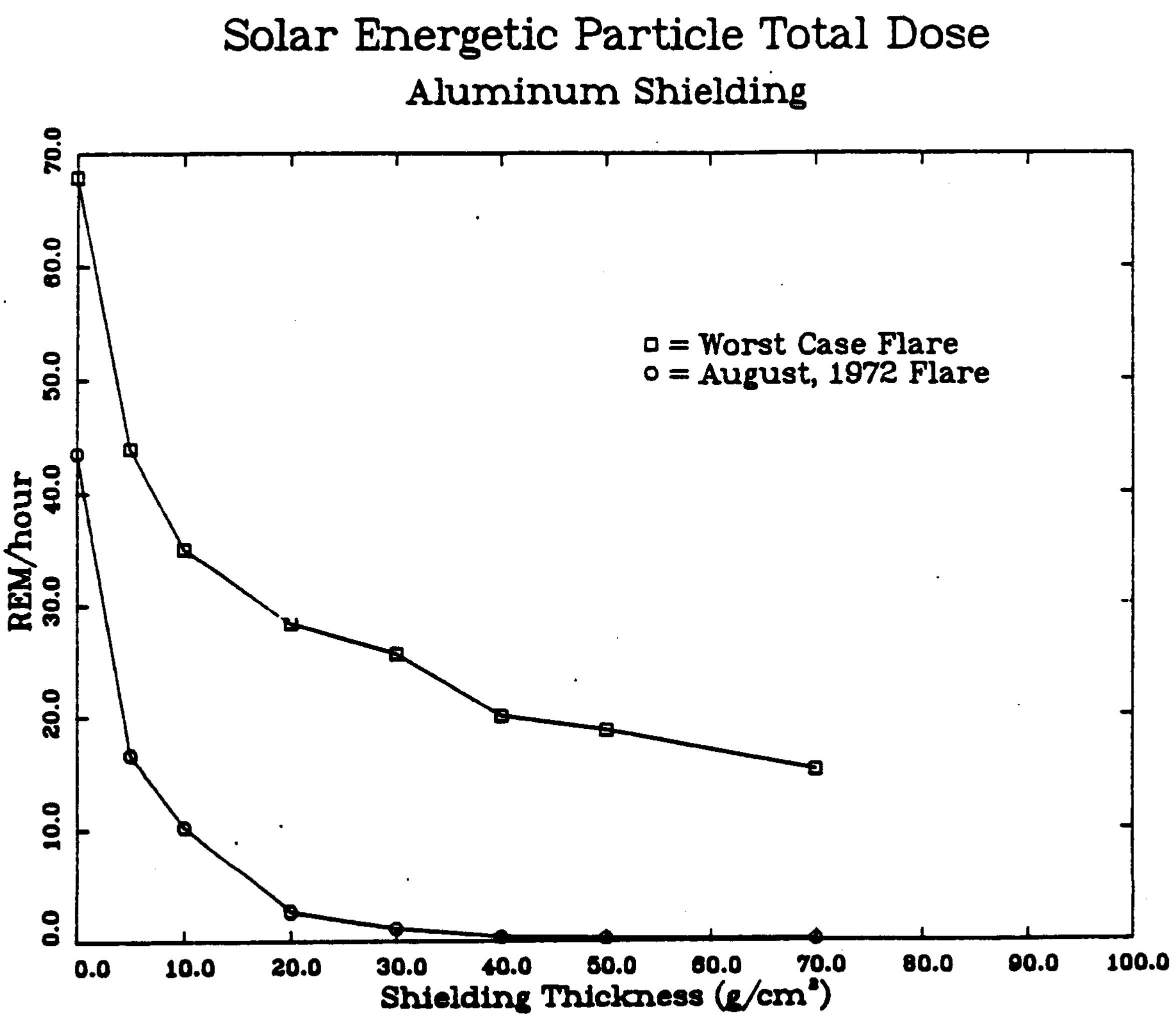
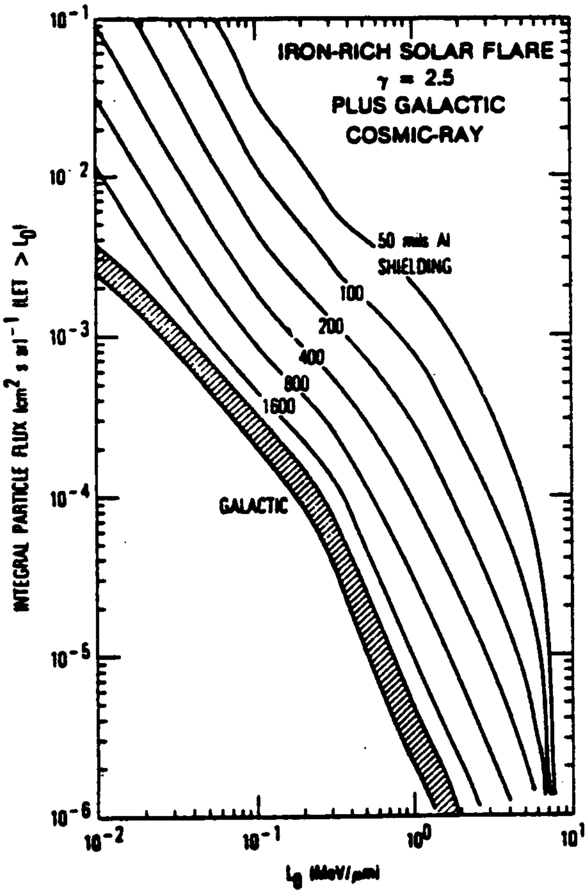


Figure 4.5.1-2 LET Spectra Versus Aluminum Shielding Depth for the Solar Heavy-Ion Event of 24 September 1977



Calculated linear-energy-transfer (LET) spectra during the peak of a flare like the 24 September 1977 event are presented for a range of shielding thickness as shown. LET spectra for the galactic cosmic ray flux at solar minimum for the same range of shielding thicknesses are indicated by the shaded region.

4.5.2 Trapped Electrons

Best-case radiation doses from trapped electrons in GEO as a function of aluminum shielding thickness have been computed by Pfitzer and Yucker and are shown in Figures 4.5.2-1, 4.5.2-2, and 4.5.2-3. The figures show calculations for bone marrow, eye lens, and skin dose respectively, found using an anatomical man model. These calculations appear to be consistent with the results of Stassinopoulos for thinner shields; however, that reference presents doses in rad_{Al}.

Calculations utilize the average trapped electron flux. Best-case dose refers to the use of optimum longitude at GEO (near midnight) to achieve minimum average electron flux. Worst-case doses exceed best-case doses by 42%. Dose enhancements during storm conditions have not been modeled.

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Figure 4.5.2-1 Best-Case Bone Dose Versus Aluminum Shielding Thickness for Trapped Electrons in GEO

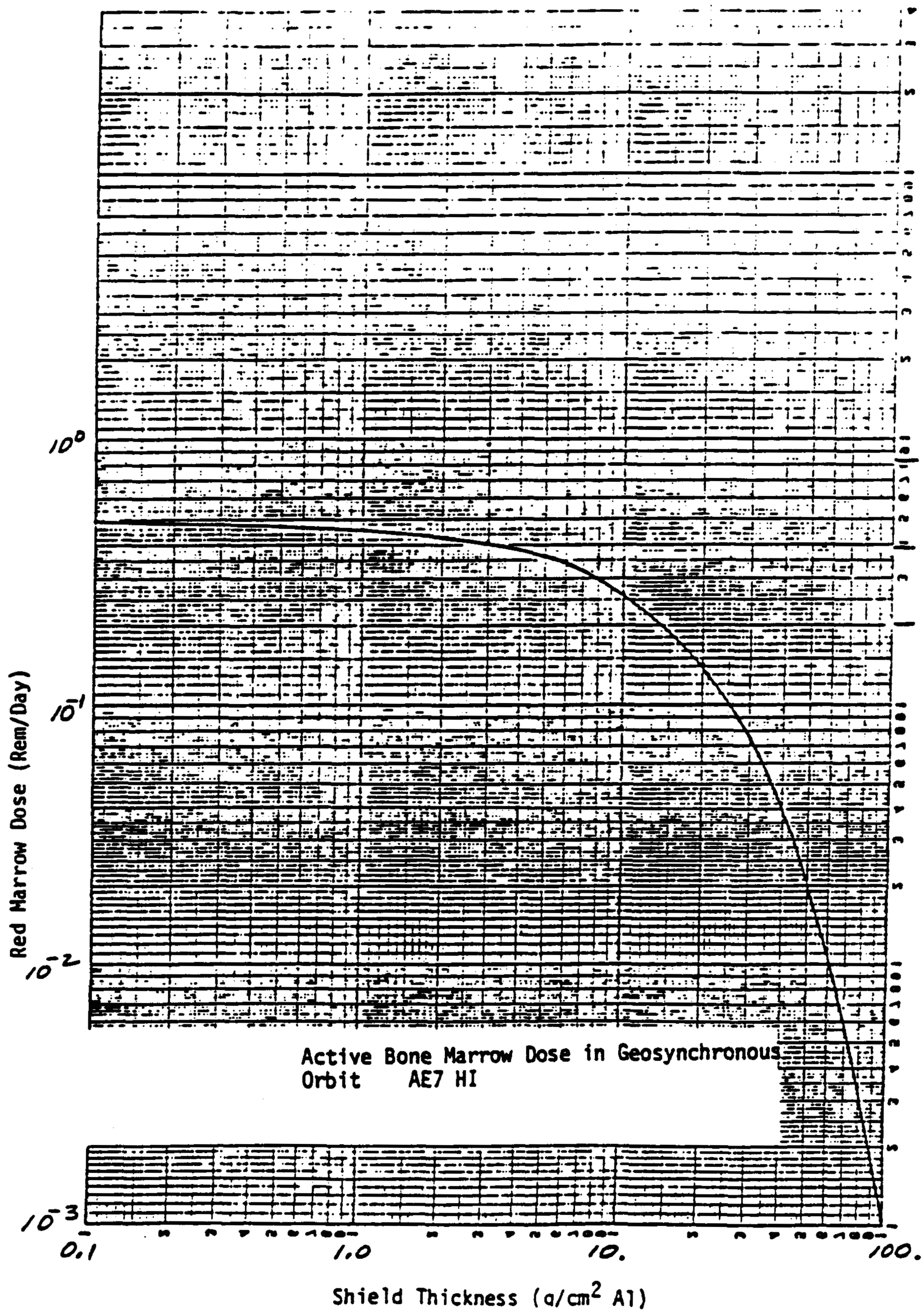

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Figure 4.5.2-2 Best-Case Eye Dose Versus Aluminum Shielding Thickness for Trapped Electrons in GEO

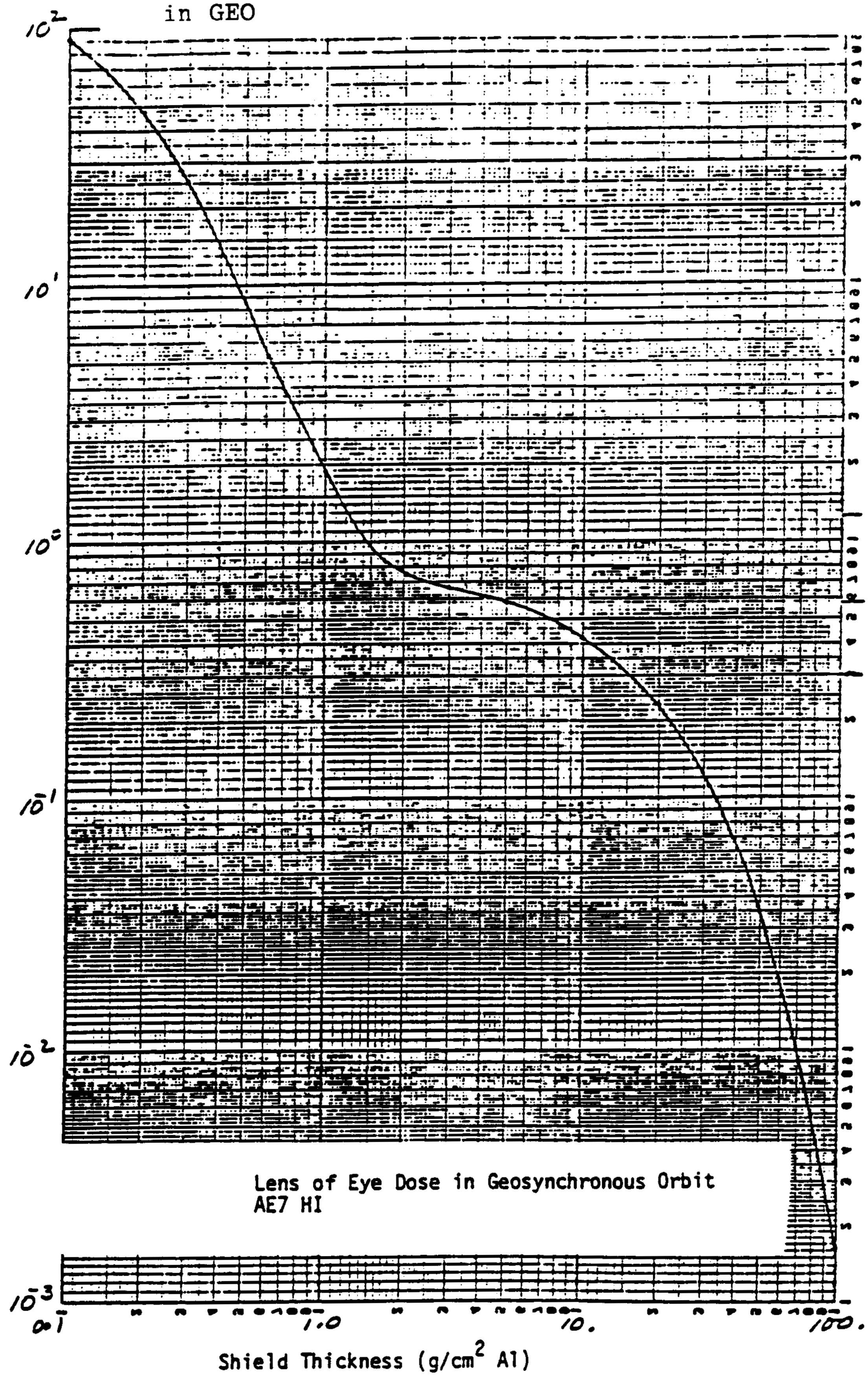

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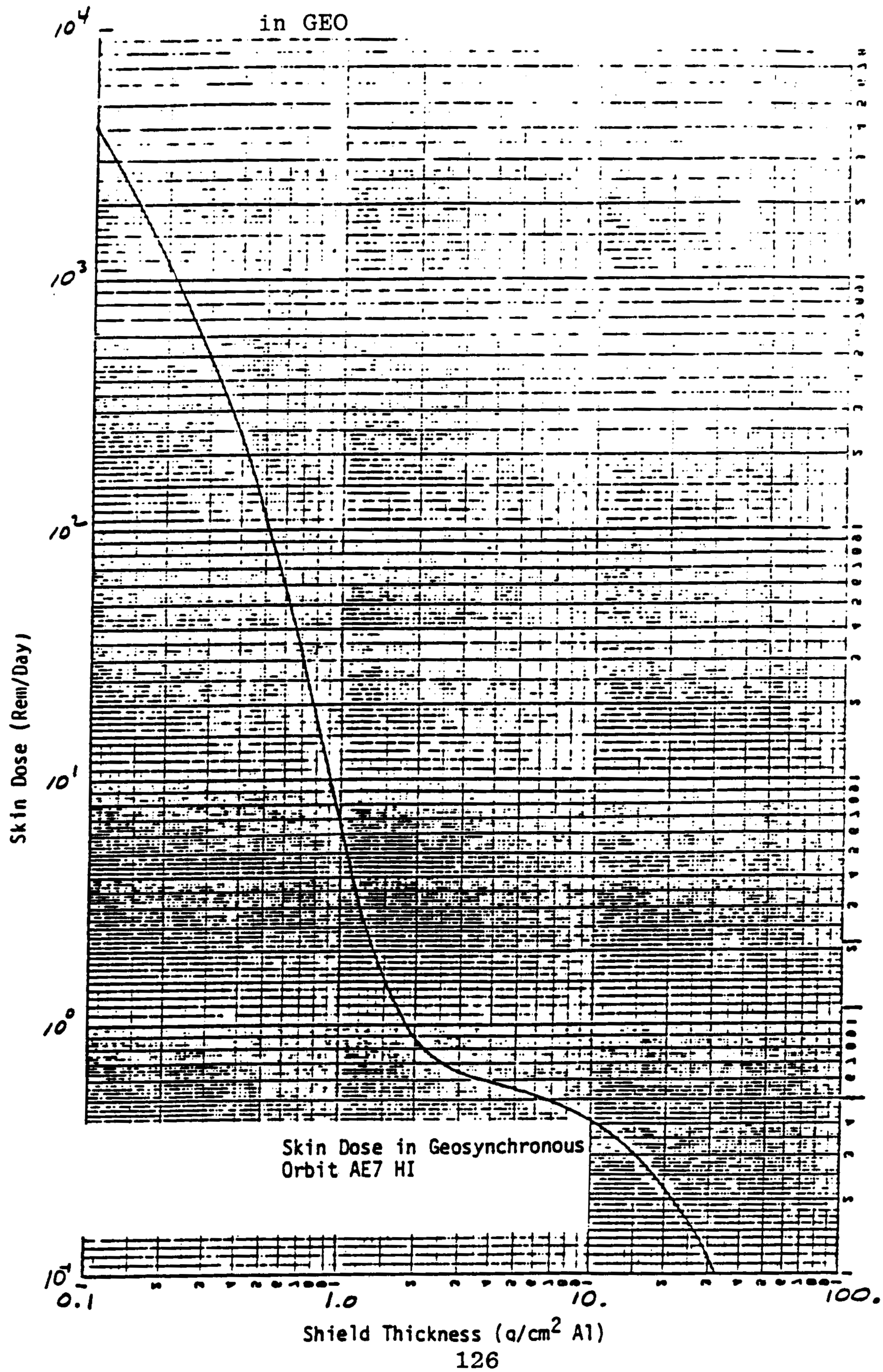
Figure 4.5.2-3 Best-Case Skin Dose Versus Aluminum Shielding Thickness for Trapped Electrons in GEO



4.5.3 Trapped Protons

Pfitzer and Yucker have estimated the best-case radiation doses for the transfer orbit from LEO to GEO (Table 4.5.3-1). Worst-case doses are 42% higher than in Table 4.5.3-1.

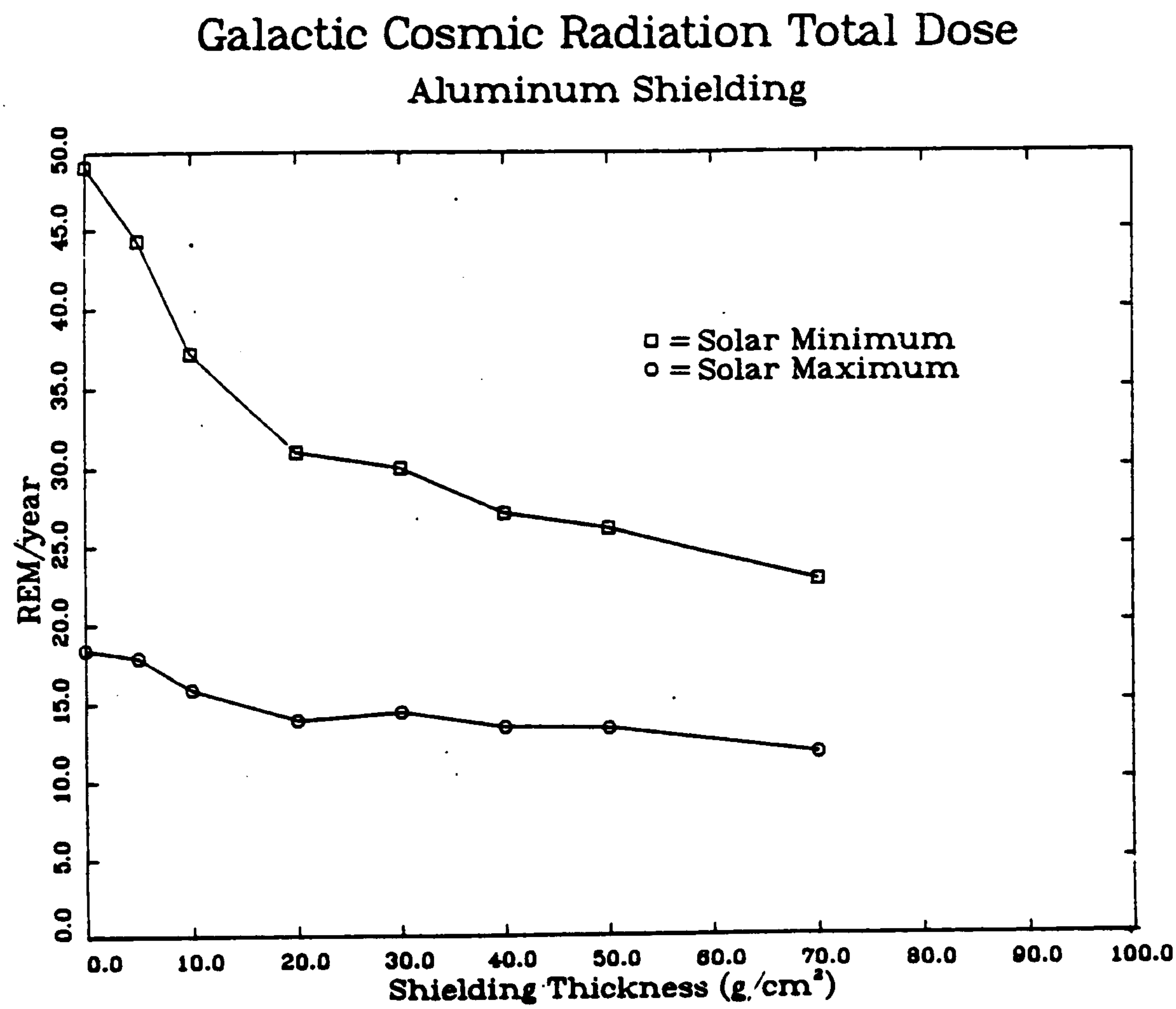
Table 4.5.3-1 Organ Doses for LEO to GEO Transfer Orbit (rem)

Shielding ($g\ cm^{-2}$ Al)	Bone (5 cm)	Eye (0.3 cm)	Skin (0.001 cm)
1.0	1.73	20.4	46.3
1.7	1.63	6.94	13.9
2.06	1.59	4.46	7.94
3.0	1.50	2.68	2.74
5.0	1.34	2.17	2.11
10.0	1.02	1.57	1.53
20.0	0.653	0.917	0.89
30.0	0.449	0.559	0.58
41.1	0.310	0.405	0.39

4.5.4 Galactic Cosmic Radiation

The dose to bone marrow versus depth in aluminum due to galactic cosmic radiation has been computed by Letaw and Clearwater and is shown in Figure 4.5.4-1. The calculation includes 5 cm tissue shielding in addition to the specified aluminum shielding thickness. Maximum dose rate occurs around solar minimum. During this period, the unshielded dose to the bone marrow is about 0.6 rem for a four-day mission to GEO. It is estimated the unshielded dose to the eye (3 mm tissue depth) is less than 1.0 rem. The skin dose may be somewhat greater depending on the exact nature of the low-energy components. It is estimated that 0.2 g cm^{-2} Al will stop most of the low-energy cosmic ray flux.

Figure 4.5.4-1 Galactic Cosmic Ray Dose Versus Aluminum Shielding Thickness at Solar Minimum and Solar Maximum



4.5.5 NCRP Dose Guidelines

Radiation dose guidelines for crewmembers of Space Station are currently under study by the National Council on Radiation Protection and Measurements (NCRP). These guidelines are defined by comparison of terrestrial occupational risks with the risks introduced by radiation exposure. The guidelines are not based on anticipated doses for any space mission. Crewmembers of the GEO mission are also Space Station crewmembers. They would presumably be subject to any Space Station guidelines ultimately adopted by NASA.

Draft guidelines have been presented by NCRP but have not yet been formally recommended to NASA (Fry). It is expected that an interim NCRP report will be published early in 1988. The recommendations of the interim report may be modified as additional radiation dosimetry results become available. Current draft NCRP guidelines are shown in Table 4.5.5-1.

Table 4.5.5-1 Draft Dose Limits for Space Station Crewmembers (rem)

Period	Bone (5 cm)	Eye (0.3 cm)	Skin (0.001 cm)
30 days	25	100	150
1 year	50	200	300
Career	100-400[a]	400	600

[a] 200 + 7.5 (Age - 30) Males
200 + 7.5 (Age - 38) Females

4.5.6 Other Dose Guidelines

Additional dose guidelines for solar energetic particle exposure may be necessary. The stochastic nature of these events, both in frequency and intensity, may impose difficult or impossible constraints on spacecraft construction and mission planning. Guidelines which compound the risk of radiation exposure with the risk of stochastic biological endpoints should, in any case, provide assurance that the success of the mission cannot be jeopardized by crewmember radiation health issues.

4.5.7 Baseline Radiation Dose

A baseline radiation dose for crewmembers on the manned GEO mission is presented in this section. The baseline dose serves as a nominal dose for crewmembers who do not participate in EVA. The difference between the baseline dose and the NCRP dose limits provides an upper limit on the radiation which can be absorbed in EVA (Effective EVA Dose Limit). The Effective EVA Dose Limit assumes that NCRP limits have not been eroded by crew activities prior to the manned GEO mission.

Assumptions of the baseline dose are as follows:

(1) Minimum shielding on the MOTV is 2 g cm^{-2} Al.
(2) Mission duration is 4 days in GEO.
(3) Mission occurs at worst-case longitude in GEO.
(4) Mission occurs during solar minimum.

Baseline radiation doses are shown in Table 4.5.7-1

Table 4.5.7-1 Baseline Radiation Dose Manned GEO Mission (rem)

Dose Component	Bone (5 cm)	Eye (0.3 cm)	Skin (0.001 cm)
LEO to GEO	1.6[a]	4.5[a]	8.0[a]
Trapped Electrons	2.4[b]	4.5[c]	5.1[d]
Cosmic Radiation	0.6[e]	0.6[e]	0.6[e]
GEO to LEO	1.6[a]	4.5[a]	8.0[a]
Total	6.2	14.1	21.7
% NCRP Limit (30 day)	25%	14%	14%
Effective EVA Limit	18.8	85.9	128.3

[a] Table 4.5.3-1, page 127
[b] Figure 4.5.2-1, page 124
[c] Figure 4.5.2-2, page 125
[d] Figure 4.5.2-3, page 126
[e] Figure 4.5.4-1, page 129

4.5.8 EVA Shielding Requirements

EVA radiation shielding requirements are presented in Table 4.5.8-1. Results are based on the Effective EVA Dose Limit in Section 4.5.7 and dose versus shielding plots in Section 4.5. Note that Table 4.5.8-1 makes no allowance for enhanced radiation fluxes during solar events or geomagnetic storms. No engineering safety factor is incorporated into Table 4.5.8-1.

Table 4.5.8-1 Minimum EVA Shielding Requirements - Manned GEO Mission (g cm^{-2} al equivalent)

Number of 10-Hour EVA Excursions	Bone (5 cm)	Eye (0.3 cm)	Skin (0.001 cm)
1	0.1[a]	0.1[a]	0.4
2	0.1[a]	0.1[a]	0.5
3	0.1[a]	0.15	0.5

[a] Shielding data are insufficient to allow a recommendation of less than 0.1 g cm^{-2} Al equivalent for any part of the body.

It may be appropriate to apply an engineering safety factor to these results because of uncertainty in the space radiation environment and dose assessment methodology. The following safety factors are recommended for <u>shielding thickness</u>:

Bone	No safety factor required; actual EVA bone dose is more than an order of magnitude below EVA limit.
Eye	Safety factor = 3; allows for a factor of 4 uncertainty in EVA eye dose computation.
Skin	Safety factor = 2; allows for a factor of 10 uncertainty in EVA skin dose computation.

The above EVA shielding requirements <u>do not</u> account for the risk of dose enhancements during storm conditions. With 0.5 g cm^{-2} shielding, skin dose is about 100 rem d^{-1} (Figure 4.5.2-3). If dose rate increases by 3 orders of magnitude over a few hours during a large geomagnetic substorm (Stassinopoulos), the skin dose rate is as much as 4000 rem hr^{-1}. A few minutes exposure at this rate would result in painful skin burns (erythema) (Langham). With 1.0 g cm^{-2} shielding, skin dose rate during the storm is 250 rem hr^{-1} allowing more than one hour to return to the MOTV. The proposed safety factors appear to allow the crewmember to avoid short-term, disabling health problems during storm conditions.

4.6 Thermal Protection

The thermal protection requirements for EVA are cited in NASA-STD-3000. The performance of in-suit thermal protective systems being planned for LEO EVA on Space Station is adequate and satisfactory. No unique mission requirements have been identified; however, simplification of the communications equipment and elimination of the "snoopy cap" should allow a reduction in the airflow over the head from that which would be required for cooling purposes in cases where the head is covered. Cooling garments with circulating water for cooling and heating and forced-air circulation have proven thoroughly effective in prior EVA missions. The requirements for thermal protection of the EVA crewmember at GEO should maintain the crewmember's skin temperature between 33° C and 34° C (91.5° F and 93.5° F) and maintain all surfaces in contact with the crewmember between 10° C and 45° C (50° F and 113° F). The cooling and heating system should be controlled automatically to a manual set-point which is operable by a crewmember who can adjust the set point to maintain thermal comfort at metabolic rates up to 450 watts (1500 Btu/hr) and as low as 100 watts (340 Btu/hr) (MDAC - EVA, 1986). The thermal protection system should be compatible with the requirements to maintain a non-condensing atmosphere that will not fog the visor and control relative humidity in the range between 40% and 70%.

4.7 GEO Safehaven and Portable Shelter

Provisions must be made for the protection of crew and essential equipment from ionizing radiation, pressurization loss, and atmospheric contamination. The safehaven concept envisioned for Space Station may well be a solution to this GEO problem; however, radiation shielding must be significantly increased to account for the lack of Earth

system protection as discussed in Section 4.7.1. A portable shelter may serve as a temporary solution for the EVA crew during unexpected bursts of radiation where emergency ingress into the mother vehicle cannot be accomplished quickly enough. The use of such a shelter would be limited to the EVA life support capacity, but would provide protection for the EVA crewmember while he or she is translating or being moved to the MOTV.

The following design for an individual portable storm shelter is proposed:

The shelter should have the size and shape of a sleeping bag. It should be constructed of heavy, plastic material capable of holding liquid (similar in composition to what water beds are made of). The shelter could be stowed rolled up in a volume of about 0.1 cubic meter. When used, the shelter would be unrolled and "inflated" with available water and, possibly, liquid waste and other available organic liquids (Water, for its weight, is a more efficient shielding material than aluminum).

The primary problem with a portable shelter is its weight. Water is probably the most practical material for use as shielding because of its availability, and because it is a liquid. It is also a more efficient particle shield than aluminum. Assume 10 cm water is equivalent to 4 cm aluminum. A calculation of the shelter weight is given below.

The shelter is box-shaped, 1 m x 2 m x .5 m on the inside. When fully inflated the shelter is surrounded by 10 cm of water. The outer dimensions are therefore
1.2 m x 2.2 m x .5 m. An individual shelter requires 850 liters, (850 kg) of water to provide full protective

capability. For three crewmembers, close packing could reduce this requirement to about 1 metric ton of water.

A storm shelter as specified above must completely cover the crewmembers. Large radiation doses can be received through small cracks. The stormshelter has life-control requirements similar to a spacesuit (with the exception of pressure control). Some provision for breathing, temperature control, and waste elimination must be made for an 8-hour stay.

If crewmembers are required to work during the emergency, protected sleeves and gloves should be provided. Plastic material approximately 5 cm thick would probably be sufficient protection for the arms. The hands should be protected with as much mass as practical. If required, a crewmember could leave the shelter briefly to perform some essential activity.

As mentioned above, it must be possible to "inflate" or erect the stormshelter in one hour or less. X-ray detectors on solar-monitoring satellites will provide this much warning of an impending particle event. During the one hour period the shelters would be attached to a reversible pump in the spacecraft and filled with water. The crewmembers would enter the shelters, start life control systems, and close the shelter entrance.

When protons are observed at the spacecraft, the fact of an event would be verified and procedures for returning to LEO would be initiated. If protons are not observed at the spacecraft within the hour, or possibly two hours, a false alarm would be assumed. Water would be pumped out of the shelters and back into the tanks. The shelters would be rolled up and stowed.

4.7.1 Radiation Storm Shelter

A storm shelter for protection from energetic protons during a solar particle event is required on the GEO mission. Letaw and Clearwater find that the dose equivalent to the bone marrow during the August, 1972 AL event exceeds 300 rem with 2 g cm^{-2} Al shielding. This dose exceeds the NCRP guidelines. More importantly, most crewmembers would show evidence of "radiation sickness," including nausea and vomiting, as early as one or two hours after exposure (Langham). Serious illness among the crew would significantly reduce their chances for safe return to Space Station.

The mission scenario assumes that less than 8 hours is required to abort the GEO mission and return to LEO. Heckman states that approximately one hour of lead time can be provided to the crewmembers using current warning technology. The storm shelter must therefore protect the crewmembers for approximately 7 hours of intense solar proton irradiation.

The baseline radiation dose to the bone marrow is 6.2 rem for the GEO mission (Section 4.5.7). NCRP limits allow up to 18.8 rem additional for a total of 25 rem during any 30 day period including the mission. If the AL event dose rate is reduced to 18.8 rem / 7 hour = 2.7 rem hr^{-1} inside a storm shelter, then NCRP limits will not be exceeded.

Letaw and Clearwater find that the dose rate with 20 g cm^{-2} Al shielding for the August, 1972 flare is 2.6 rem hr^{-1}. Subtracting the nominal 2 g cm^{-2} shielding in the baseline dose estimate, a storm shelter with 18 g cm^{-2} (6.7 cm of aluminum) shielding is required. A storm shelter that is large enough for one man and shielded to this specification has a mass of approximately 3.5 metric tons.

A worst-case AL event combining the high intensity of the August, 1972 event with the hard spectrum of the February, 1956 event suggests that much thicker shielding is needed for the storm shelter (Letaw). Exposure to this flare for a 7 hour period behind 70 g cm^{-2} (26 cm of aluminum) shielding results in an absorbed dose exceeding 100 rem. Presently, shielding recommendations are not based on this model because it is hypothetical and possibly overly conservative.

The storm shelter required for protection from AL proton events also provides adequate protection from OR events, heavy ions in solar particle events, and enhanced electron fluxes during geomagnetic storms. All of these storm conditions require use of the shelter.

4.8 Propulsion System Assessment

Contamination and damage to the EVA crew and the vehicles upon which they may be working are factors that must weigh heavily in design decisions for EVA and OTV propulsion systems. Clearly highly toxic and corrosive propellants pose a significant hazard while a suited crewmember is working around a satellite or other space vehicle. Therefore, designers should consider inert cold gases or propellants whose products of combustion are benign, or provide for disposable shielding between the propellants and the crewmember.

4.9 Communications Interface Requirements

Audio communications between EVA crewmembers and between EVA and IVA crewmembers must be at least redundant. Loss of audio communications between crewmembers should be grounds for termination of EVA activities. Communications between the ground and the IVA/EVA crew is also necessary. System

design should allow duplex operation with voice-activated (VOX) or push-to-talk modes available.

Video and data communication between the EVA and IVA crew is required in order to provide support information in the form of video and/or data for the EVA crew. CCTV coverage of the EVA working area is required for documentation and to allow IVA and ground monitoring for safety reasons.

The candidate system configuration and options being considered are as follows:

EVA links can be of the same standard configuration modulation formats as those which would be used in the vicinity of Space Station.

Voice operations should be duplex.

EVA-to-EVA voice communications can be relayed through the MOTV except for an emergency or privacy mode which is direct EVA-to-EVA and may be simplex on KU or KA bands.

RF power level of EVA and MOTV vehicle should each be variable from less than one watt to perhaps 4 watts.

Detailed consideration should be given to operating RF levels, since EVA personnel are exposed to a continuous field of duplex transmissions and emissions from the serviced as well as the servicing (MOTV) vehicles. In addition to interference considerations, possible damage of RF link receiver front ends may limit acceptable emission levels. RF spectrum assignment will probably be KU band. KA should be considered to reduce interference with commercial communications satellites and TDRSS. This determination will be greatly influenced by requirements of spacecraft proximity operations.

Individual channel frequencies should be assigned prior to a mission based on channel content and interference considerations.

EVA to MOTV link is a single integrated digital transmission which includes voice, video, biomedical or EVA vehicle telemetry, and command/control signals (for control of text and graphics, for example).

The EVA-to-MOTV channel width is assigned based on the type of television to be used. The range will be between 1 and 22 Megabits depending on the video content which is the predominant factor.

The MOTV-to-EVA link should be digital and include voice, text and graphics, and remote command or control functions.

The voice bandwidth must be sufficient to provide quality consistent with the requirements of the voice access/control algorithm in use. Since digital television takes up a large amount of bandwidth, there is not much advantage to economizing greatly on the bandwidth used for voice. Therefore, a simple 64-KB PCM voice signal could be reasonably accommodated. It is probable, however, that a standard 32-KB delta-modulated voice signal is sufficient and a good compromise.

EMU and MOTV antennas will consist of an array of several antennas critically located about each vehicle in order to radiate as near an omnidirectional signal as possible. Automatic selection and switching will probably be necessary.

Range and range-rate from the EVA to a target will probably be derived through processing within the "Smart" TV camera now under study.

4.10 Crewmember Autonomy

The IVA/EVA team must be permitted to operate autonomously with support, as required, from the ground and/or Space Station. Task planning, of course, must be done premission with full participation of ground and Space Station experts. Once the mission has begun, however, operational decisions must be made by the IVA/EVA team in situ.

4.11 Dedicated EVA Hardware Servicing Area

An area designated specifically for servicing EVA hardware must be located either in or next to the airlock. This work station must contain all restraint systems, tools, and consumables necessary for the accomplishment of post-EVA equipment/system servicing and repair and EVA preparation activities.

4.12 Airlock Interfaces

Two classes of airlocks are discussed in support of EVA operations at GEO. One type will serve as EVA crew airlocks and the other will serve as equipment airlocks.

4.12.1 Crew Airlocks

The crew airlock is required to support the MISTC docking, storage resupply, and crew ingress and egress. In the reference MOTV/MISTC configuration, the airlock is a double bulkhead at the ingress/egress port of the MISTC and the secondary bulkhead at a sliding door in the MOTV skin. This permits redundancy in the airlock pressure boundaries and eliminates the need to pressurize the airlock spaces upon ingressing or egressing the MOTV. The primary pressure boundary is between the MISTC and the MOTV, and there is no

or very low operating pressure difference between these two. Once the crewmember enters the MISTC, the docking hatches close at the MISTC and MOTV interior. The outer MOTV airlock hatch is opened and he or she leaves the airlock. In this mode there is no requirement to pressurize the interior airlock space.

The airlock should have the capability to be pressurized in the event of a mating failure between the MISTC and the MOTV docking hatch or in the event of crewmember incapacity or rescue of an injured crewmember. The capability to pressurize the airlock space is also required in the event of a pressure leak in the MISTC and to allow the crewmember to be stabilized in the event of depressurization.

The crew airlocks are required to accommodate the assisted docking of a disabled crewmember by the other EVA crewmember.

The airlock should be equipped with for visual monitoring of activity inside the airlock. Where direct viewing is precluded, television should be employed.

The airlock should contain the necessary apparatus for resupplying the MISTC consumables such as propulsion system cold gas, electrical power, contamination shields, and external cleaning wipes. Consumables that are on the interior of the MISTC can be replaced through the docking hatch airlock from the MOTV interior.

The crew airlock will require docking aids to permit the crewmember to align the MISTC for proper mating to the MOTV primary airlock.

4.12.2 Equipment Airlocks

To facilitate in-orbit repair and refurbishment of equipment it may be necessary to remove equipment to the MOTV interior work spaces. Conversely, if equipment or tools stored inside the MOTV are appropriate to an EVA operation, they will have to be passed from the MOTV to the external environment. These activities are accomplished through the equipment airlock.

The equipment airlock should be sized to accommodate the largest piece of equipment planned for in-orbit refurbishment by shirt-sleeved, workbench operations.

Another possible consideration for the equipment airlock size requirements should be the transfer of crewmembers from a disabled MOTV via a personal rescue device. This would require that the equipment airlock be sized to accommodate the largest crewmember and a personal portable rescue device.

The equipment airlock should contain restraints and tethers to permit a secure passage from one environment to the other. It should be designed so that any one access hatch can be opened at a time, and so the interior hatch faces in the closed position or is closed by cabin pressure. The exterior hatch should be able to be opened only when the atmosphere has been evacuated from the equipment airlock and only when the interior hatch is securely locked.

The equipment airlock should contain lighting and viewing systems for use by both the IVA and EVA crewmembers.

4.13 Concept Sketches for an Advanced EVA Enclosure

To afford environmental protection, offer room for motion and arm and hand use within the EVA enclosure, and provide translation capability, propulsion, and a stable work platform from which to perform EVA at GEO, the following MISTC is shown as a strawman enclosure for use at GEO. Figures 4.13-1 and 4.13-2 show concept sketches of the MISTC.

The MISTC system is meant to fulfill the human and environmental requirements encountered in some advanced EVA missions. However, it is not proposed as a final solution or a preliminary design for such an enclosure.

Attempts have been made to accommodate the following:

1. Ease of ingress and egress,
2. Large field-of-view,
3. Manipulator assistance of docking arms,
4. External lighting,
5. Video sensing and display,
6. Thruster propulsion,
7. Ample room to extract arms from the suit and attend to eating, drinking, waste management, and resting,
8. Environmental protection, including nominal radiation.

The enclosure is ingressed and egressed through a port at the top rear, which also serves as a docking and rescue port. The concept provides for extendible and retractable controls for managing the thrusters and manipulators. The lower half section can be equipped with grapple fixtures to provide RMS mating, probably at the seat or foot location.

Attach points for materials and tool kits are provided on the lower section. The torso is a flexible joint concept,

much like a bellows, which enables the crewmember to bend at the trunk. The life support and propulsion consumables are modularly connected and replaced, although the volume for such tasks is not depicted in the sketches.

Since mission time is extremely valuable, it is essential to provide a configuration of the EVA MISTC that allows as rapid a turnaround as possible between uses. It is suggested that consumables be replaced in modular or tank form, rather than refilling integral tankage through a high pressure service umbilical. This suggestion is offered for the following reasons:

If integral tankage is used, it will probably operate at very high pressures to provide maximum capability with minimum stowage volume. Safety considerations demand a heavily armored flex line at these pressures. Furthermore, careful attention must be given to cleanliness to prevent a catastrophic explosion of the entire system by high speed microscopic particles in the air flow. The power of such an event during the GEO mission would likely destroy the satellite being repaired, the EVA system, and the MOTV.

Additionally, the tendency of high pressure lines to straighten themselves out presents a real mechanical challenge and more opportunity for accidents. The time required for transfer of the significant quantities of consumables through adequate umbilicals is counter-productive to fast turnaround.

It is proposed that entire high pressure cylinders be changed out by breaking their flow circuit downstream of a primary regulator which remains with the cylinder. The high pressure interface of this regulator would have been connected to the cylinder under far more ideal conditions in a protected servicing area of Space Station. The output of

the primary regulator, in conjunction with any desired redundant systems, would provide all the material required for the normal low level regulators to function properly.

Consideration should be given to battery change-out versus in-place charging for safety, weight, and turnaround time reasons (smaller batteries are more quickly exchanged). Very high energy-density batteries improperly charged or handled are highly explosive. The unexpected destruction of part of the JSC battery laboratory and the explosion of lithium cells in emergency locator transmitters within a number of aircraft demonstrate the potential hazards when working with unusually high energy-density storage. A scenario for consideration includes a rapid change-out of the EVA battery pack with charging taking place, within the MOTV, over a an optimum period and under precisely controlled conditions.

Some discussion has focused on providing a third arm equipped with a power tool or manipulator effector which can be operated in a bare-handed mode (that is, the controls placed inside at the end of the arm and the tool mounted on the outside end of that arm).

EVA worksite interface requirements include EVA lighting and video cameras. Some consideration of these features could be shown in the MISTC sketches. One present EVA embodiment of these two features, typically used with the EEU, has both built into the helmet assembly, but on the outside of the visor. In a proposed MISTC, the lights should be on the outside of the enclosure to eliminate internal reflection. The video camera should also be on the outside to reduce reflections, optical distortion, and the effects of sun shielding or attenuation. The miniature camera will probably require a remotely controlled or voice actuated pan and tilt mounting.

The upper section of the EVA enclosure has also been incorporated in the hybrid workstation of the MOTV. The upper portion is mounted on a turret swivel and permits a crewmember to manually interact with the local environment through the arms. The operator "sits" in a restraint or stands on a restraint platform within the IVA environment.

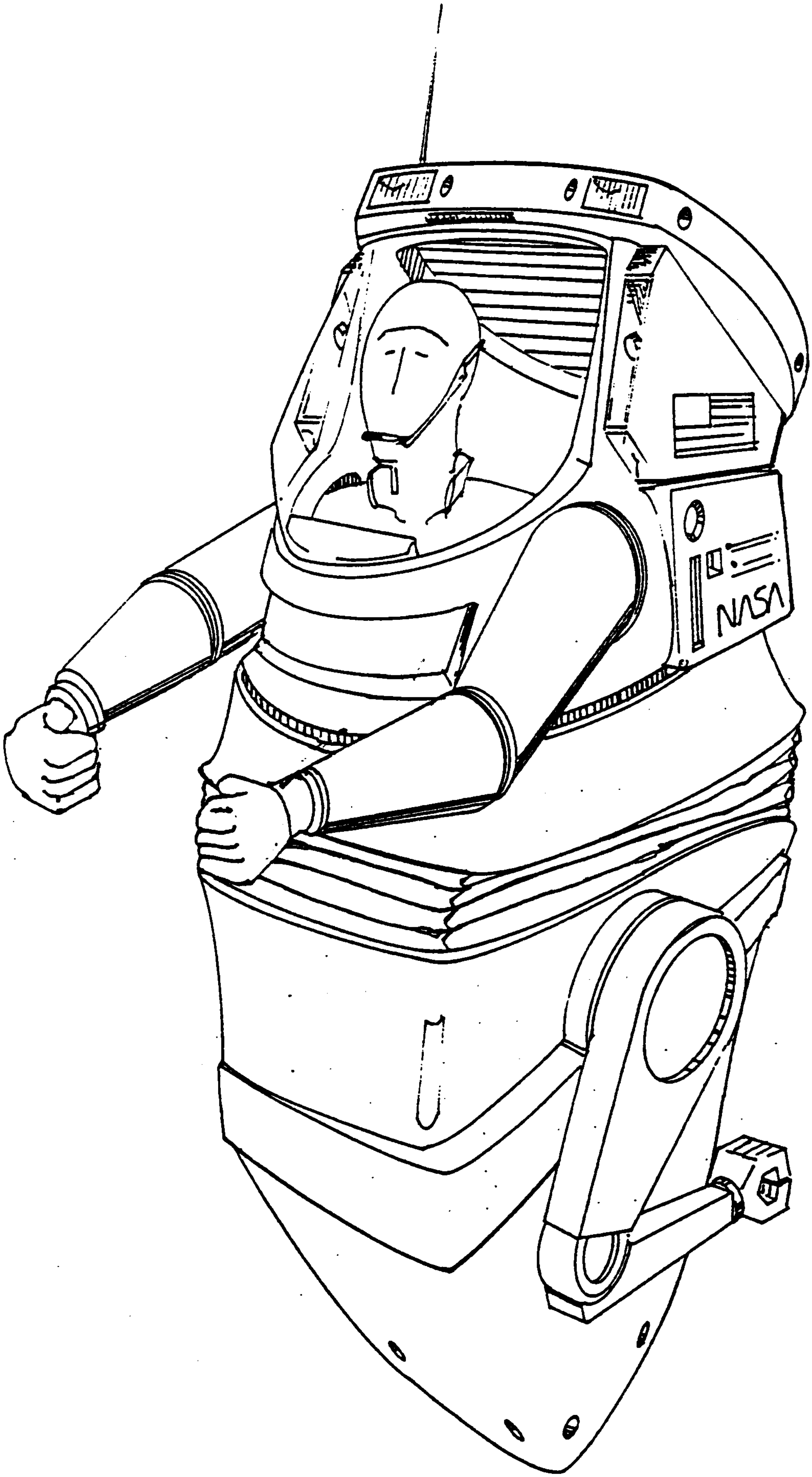


Figure 4.13-1 MISTC Strawman Concept

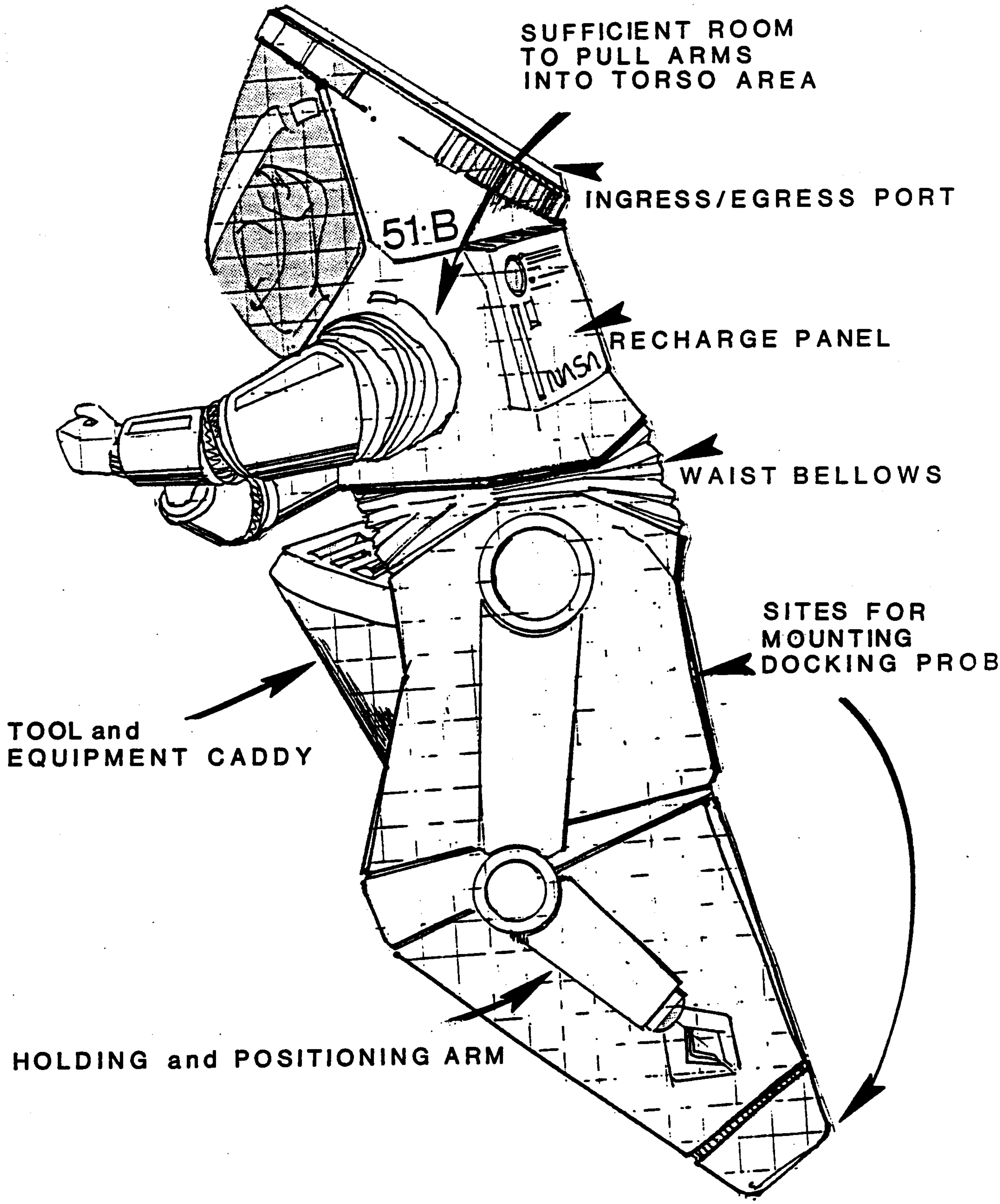


Figure 4.13-2 MISTC Strawman Concept

5.0 BIBLIOGRAPHY

Adams, J. H., Silverberg, R. and Tsao, C. H. Cosmic ray effects on microelectronics, part I: the near-Earth particle environment, NRL Memorandum Report 4506, Naval Research Laboratory, Washington, D.C., 1981.

Adolph, E. F. Qauntitative relations in the physiological constitutions of mammals, Science 109, 1949, pp. 579-585.

Andersen, M. E. Saturable metabolism and its relationship to toxicity, CRC Crit. Reviews Toxicol, 1981, pp. 105-150.

Andersen, M. E., Gargas, M. L., Jones, R. A. and Jenkins, L. J., Jr. Determination of the kinetic constants for metabolism of inhaled toxicants in vivo using gas uptake measurements, Toxicol Appl. Pharmacol. 54, 1980, pp. 110-116.

Barnea, G., Berger, M., Jr. and Seltzer, S. M. Optimization study of electron - Bremsstrahling shielding for manned spacecraft, Journal of Spacecraft and Rockets, Vol. 24, No. 2, March-April 1987, pp. 158-161.

Benton, E. V., et al. Radiation measurements aboard Spacelab I, Science 13, July 1984.

Boeing. Advanced EVA system design requirements study, March 1986.

Brown, N. E., Dashner, T. R. and Hayes, B. C. Extravehicular activities guidelines and design criteria, CR-2160, National Aeronautics and Space Administration-George C. Marshall Space Flight Center, Huntsville, Alabama, January 1973.

Burrell, M. O. The risk of solar proton events to space missions, in Proceedings of the 1971 National Symposium on Natural and Manmade Radiation in Space, NASA TMX-2440, National Aeronautics and Space Administration, Washington, D.C., 1971, pp. 310-323.

Calder, N. Spaceships of the mind, Viking Press, New York, 1978.

Chenette, D. L. and Dietrich, W. F. The solar flare heavy ion environment for single-event upsets: a summary of observations over the last solar cycle 1973-1983, IEEE Trans. Nucl. Sci. NS-31, 1984.

Chobotov, V. A. Classification of orbits with regard to collision hazard in space, AIAA Journal of Spacecraft, Vol. 20, No. 5, September 1983.

Cohen, M. M., and Bussolari, S. Human factors in space station architecture II, 86856, National Aeronautics and Space Administration, Washington, D.C., April 1987.

Coleman, M. E. Toxicological safeguards in the manned Mars missions, N87-17781, National Aeronautics and Space Administration-George C. Marshall Space Flight Center, May 1986.

Cuccinell, S. A. and Pitts, C. M. Thrombosis at mountain altitudes, Aviation, Space and Environmental Medicine, November 1987, pp. 1109-1111.

Dedrick, R. L. Animal scale-up, J. Pharmacokinetics and Biopharmaceutics 1, 1973, pp. 435-461.

Dedrick, R. L. and Bischoff, K. B. Species similarities in pharmacokinetics, Federation Proceedings 39, 1980, pp. 54-49.

Duke, M. E., and Keaton, P.W., eds. Manned Mars missions - a working group report, NASA M001, NASA M002, National Aeronautics and Space Administration/GPO, 1985.

Farhi, L. E. Gas stores in the body, W. O. Fenn and H. Rahn, eds., in Handbook of Physiology, Vol. I, Sec. 3, Respiration, American Physiological Society, Washington, D. C., 1964, pp. 873-885.

Fink, D. (Chair). The role of man in geosynchronous orbit. National Aeronautics and Space Administration Advisory Council, NASA Headquarters, Washington, D. C., February 1987.

Fisher, H. T. Space station and EVA transportation, International Center for Transportation Studies, July 1986.

Ford Aerospace and Communications Corporation. Geostationary platform bus study final report, volume II - comprehensive report, Ford Aerospace and Communications Corporation, September 1986.

Fry, R. J. M. Reevaluation of dose limits for space workers, presented at the NATO Advanced Study Institute on Terrestrial Space Radiation and its Biological Effects, Corfu, Greece, October 11-25, 1987.

Furr, P. A. Probability of oxygen toxicity using an 8 psi space suit, Aviation, Space and Environmental Medicine, September 1987, pp. A113-A120.

Gerlowski, L. E. and Jain, R. K. Physiologically based pharmacokinetic modeling: principles and applications, J. Pharmaceut. Sci. 72, 1983, pp. 1103-1127.

Graybiel, A., ed. Basic environmental problems of man in space, Pergamon Press, New York, November 1973.

Grumman Corporation. Advanced EVA system design requirements study, Grumman Corporation, Beth Page, Long Island, December 1985.

Hall, S. B. The human role in space, Noyes Publications, Park Ridge, NJ, 1985.

Hall, S. B. and McCann, M. E. Radiation environment and shielding for early manned Mars missions, N87-17780, National Aeronautics and Space Administration-George C. Marshall Space Flight Center, Huntsville, Alabama, May 1986.

Hansson, P. A. Free radical assessment - a safe route to space.

Heckman, G., Hirman, J., Kunches, J. and Balch, C. The monitoring and prediction of solar particle events - an experience report, Adv. Space. Res., 1985.

Heckman, G. Solar particle event predictions for manned Mars mission, Manned Mars Missions (Working Group Papers), NASA M002, Workshop at George C. Marshall Space Flight Center, Huntsville, Alabama, June 10-14, 1985, National Aeronautics and Space Administration, Washington, D.C., 1986.

Himmelstein, K. J. and Lutz, R. J. A review of the applications of physiologically based pharmacokinetic modeling, J. Pharmacokinetics and Biopharmaceutics 7, 1979, pp. 127-145.

Hord, R. M. Handbook of space technology: status and projections, CRC Press, Inc., Boca Raton, Florida, 1985.

Horrigan, D. The toxic effects of chronic exposure to low levels of carbon dioxide, Publication No. 973, Naval Submarine Medical Research Library, January 19, 1982.

Hueter, U. Manned Mars mission environmental control and life support subsystems, N87-17797, National Aeronautics and Space Administration-George C. Marshall Space Flight Center, Huntsville, Alabama, May 1986.

Inderbitzen, R. S. and Decarlis, J. J., Jr. Energy expenditure during simulated EVA workloads, SAE Paper 860921, July 1986, pp. 109-112.

Johnson, L. B., Sander, E. and Lebow, S. NASA list of potential space tools and equipment, NASA CR-1760, National Aeronautics and Space Administration, Washington, D.C., May 1971.

Johnson, P. C. Adaptation and readaptation, medical concerns of a Mars trip, N87-17770, National Aeronautics and Space Administration-George C. Marshall Space Flight Center, Huntsville, Alabama, May 1986.

JSC Memorandum. Radiation Analysis of Candidate Extravehicular Activity (EVA) Space Suit Material Layups, Johnson Space Center, Houston, Texas, May 1987.

Kakitsuba, N. and Mekjavic, I. Determining the rate of body heat storage by incorporating body composition, Aviation, Space and Environmental Medicine, Vol. 58, No. 4, April 1987, pp. 301-307.

King, J. H. J. Solar proton fluences for 1977-1983 space missions, Spacecraft 11, 1974, pp. 401-408.

Kosmo, J. J. and Tri, T. O. Space Station EVAs systems (EVAS) description preliminary user and interface guidelines document, Lyndon B. Johnson Space Center, Crew Systems Branch, Houston, Texas, June 1987.

Kreith, F. Principles of heat transfer, 3rd edition, IEP - a Dun-Donnelly Publisher, New York, 1976.

Langham, W. H. Radiobiological factors in manned space flight, National Academy of Sciences, Washington, D.C., 1967, p. 247.

Letaw, J. R. and Clearwater, S. H. Radiation shielding requirements on long-duration space missions, Severn Communications Corporation Report 86-02, Severn Communicatons Corporation, Severna Park, Maryland, 1986.

Lewis, J. L. Design criteria for STS suit EVA reach envelope, NASA report TM-EW53-79-124M, Lyndon B. Johnson Space Center, Houston, Texas, October 1979.

Lienhard, J. H. A heat transfer textbook, Prentice-Hall, Inc., 1981.

Lockheed Astronautics Division. Geostationary platform bus study, interim report, LMSC-DO60799, Lockheed Missiles and Space Company, Inc., Sunnyvale, California, April 1986.

Lockheed Astronautics Division. Geostationary platform bus study, contract extension final review, NAS8-36103, Lockheed Missiles and Space Company, Inc., Sunnyvale, California, December 1986.

Lockheed Missiles and Space Company. Space station human productivity study, LMSC FO 60784/1-4, Lockheed Missiles and Space Company, Inc., Sunnyvale, California, November 1985.

Lockheed Engineering and Management Services. Satellite services catalog tools and equipment, JSC-19211, National Aeronautics and Administration, Lyndon B. Johnson Space Center, Houston, Texas, November 1983.

Lovelace Foundation for Medical Education and Research, Albuquerque, New Mexico. NASA report for contract NASA 9-7009, Section A, to Manned Spacecraft Center, Houston, Texas, December 28, 1971.

Lovelace Foundation for Medical Education and Research, Albuquerque, New Mexico. NASA report for contract NASA 9-12572, Part III, to Manned Spacecraft Center, Houston, Texas, February, 1975.

Luft, U. C. Aviation physiology - the effects of altitude, Handbook of Physiology, Sec. 3, Respiration, Vol. II, edited by W. O. Fenn A. Rahn, American Physiological Society, Washington, D. C., 1965, pp. 1099-1145.

Luft, U. C. Laboratory facilities for adaptation research: low pressures, Handbook of Physiology, Sec. 4, Adaptation to the Environment, edited by D. B. Dill, American Physiological Society, Washington, D. C., 1964, pp. 329-341.

Martin, M. F. Orbital equipment transfer techniques survey of representative transfer cases and equipment transfer techniques, National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama, November 17, 1986.

McCormack, P. D. Radiation hazards in low-Earth orbit, polar and geosynchronous orbits and deep space, June 1987.

McDonnell Douglas. Advanced EVA system design requirements study, January 1986.

McDougal, J. N., Jepson, G. W., Clewell, H. J., III and Anderson, M. E. Dermal absorption of dihalomethane vapors, Toxical, Appl. Pharmacol. 79, 1985, pp. 150-158.

McKay, C. P. The case for Mars II, Science and Technology Series, Vol. 62, American Astronautical Society, San Diego, California, 1985.

Marton, T., Rudek, F., Miller R. and Norman, D. Handbook of human engineering design data for reduced gravity conditions, NASA CR-1726, National Aeronautics and Space Administration, October, 1971.

National Aeronautics and Space Administration, Lyndon B. Johnson Space Center. Shuttle EVA description and design criteria, JSC-10615(B), Lyndon B. Johnson Space Center, Houston, Texas. *PRELIMINARY

National Oceanic and Atmospheric Administration. Descriptive text - contents of preliminary report and forecast of solar-geophysical activity, June 9, 1987.

National Space Science Data Center. The AE4 model of the outer radiation zone electron environment, NSSDC 72-06, Greenbelt, Maryland, 1972.

NASA Scientific and Technical Information Office. Bioastronautic Data Book, 1973.

NASA - STD-3000. Man-systems integration standards, National Aeronautics and Space Administration, Washington, D.C., March 1987.

NASA Johnson Space Center - Engineering Directorate. Space station audio system derived requirements, Doc. EE-2-87-005 (U), Rev. A, April 10, 1987.

NASA Johnson Space Center - Engineering Directorate. Space station television subsystem, preliminary design concepts, Doc. EE-2-87-001, April 28. 1987.

NASA Johnson Space Center. Space station medical sciences concepts, NASA Technical Memorandum 58255, February 1984.

Nash, J. O. and Wilde, R. C. Study of EVA operations associated with satellite services, NASA-CR-167614, National Aeronautics and Space Administration, April 1982.

Naval Submarine Medical Research Laboratory. Position paper: the toxic effects of chronic exposure to low levels of carbon dioxide, January 1982.

Nicogossian, A. E. Human capabilities in space, Publication No. TM-87360, National Aeronautic and Space Administration, Washington, D.C., 1984.

Oberg, J. E. and Oberg, A. R. Pioneering space living on the next frontier, McGraw Hill Book Company, New York, 1986.

Pfitzer, K. A. and Yucker, W. R. Final report: extravehicular crewman work system study, Appendix A: Radiation Environment, McDonell Douglas Astronautics Company - West, Huntington Beach, California, 1978.

Popovich, Gubinsky, and Kolesnikov. Ergonomic support of cosmonaut activity, FTD-ID-(RS)T-1238-86, translated by Foreign Technology Division, Air Force Systems Command, March, 1987.

Pruett, E. C., Kirkpatrick, M., Malone, T. B. and Shields, N. L., Jr. Development and verification of shuttle payload extravehicular activity requirements, H-76-4, Essex Corporation, Huntsville, Alabama, March 1976.

Rahn, H. and Fenn, W. O. The graphical analysis of the respiratory gas exchange: the O_2 - CO_2 diagram, American Physiological Society, Washington, D.C., 1955.

Ride, S. K. Leadership and America's future in space. National Aeronautics and Space Administration, Washington, D. C., August 1987.

Roesh, J. R. Handgrip performance with the bare hand and in the extravehicular activity glove, JSC-22476, National Aeronautics and Space Administration/Lyndon B. Johnson Space Center, Houston, Texas, February 1987.

Roth, E. M. Compendium of human responses to the aerospace environment, Vol. III, Sections 10-16, NASA Contractor Report, NASA CR-1205 III, Lovelace Foundation for Medical Education and Research, November 1968.

Santy, P. A. Manned Mars mission psychological issues, N87-17774, National Aeronautics and Space Administration-George C. Marshall Space Flight Center, Huntsville, Alabama, May 1986.

Schaffer, Abelles and Olsen. The roles of astronauts and machines for future space operations, A86-23521, AIAA, SAE, ASME, ALCLE, ASMA Conference on Environmental Systems, July 1985.

Schmitt, H. H. Human adaptation and readaptation for Mars mission, N87-17771, National Aeronautics and Space Administration-George C. Marshall Space Flight Center, Huntsville, Alabama, May 1986.

Schmitt, H. H. and Reid, D. J. Anecdotal information on space adaptation syndrome. National Aeronautics and Space Administration/ Space Biomedical Research Institute USRA/Division of Space Biomedicine, July 1985.

Shields, N. L., Jr. Analysis of large space structures assembly, NASA-CR-3751, National Aeronautics and Space Administration-George C. Marshall Space Flight Center, Huntsville, Alabama, December 1983.

Silverberg, R., Tsao, C. H., Adams, J. H., Jr. and Letaw, J. R. Radiation hazards in space, Aerospace America, October 1987.

Smith, R. E. and West, G. S. Space and planetary environment criteria guidelines for use in space vehicle development, 1982 Revision, Vol. 1, National Aeronautics and Space Administration, STIB, George C. Marshall Space Flight Center, Huntsville, Alabama, 1983.

Space Science Board, National Academy of Sciences and National Research Council. Human factors in long-duration spaceflight, National Academy of Sciences, Washington, D.C., 1972.

Stassinopoulos, E. G. The geostationary radiation environment, J. Spacecraft 17, 1980, pp. 145-152.

Stramler, J. H. A comparison of four space-suited and non-space-suited reach envelope conditions: a pilot study, National Aeronautics and Space Administration/ Lyndon B. Johnson Space Center, Houston, Texas, January 1987.

Trevino, R.C. and Fullerton, R. K. EVA catalog tools and equipment, National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas, November 4, 1985.

Vernov, S. N., Logachev, Yu. I. and Pisarenko, N. F. Physical characteristics of interplanetary space, in Foundations of Space Biology and Medicine, M. Calvin and O. G. Gazenko, eds., Vol. I (Space as a Habitat), Chapter 2, National Aeronautics and Space Administration, Washington, D.C., 1975.

Waligora, J. M. The physiological basis for spacecraft environmental limits, 1045, National Aeronautics and Space Administration, Washington, D. C., 1979.

Waligora, J. M. and Sedej, M. M. Physiological and technological considerations for Mars mission EVA, N87-17798, May 1986.

Wise, J. A. The quantitative modeling of human spatial habitability, NASA-CR-179716, December 1985.

Wolbers, H. The human role in space, methodology validation study, NAS8-35611, McDonnell Douglas Astronautics Company, Huntington Beach, California, February 1986.

Zimcik, D. G. Effect of long-term exposure to LEO space environment on spacecraft materials, Vol. 33, No. 1, Canadian Aeronautics and Space Journal, March 1982.

6.0 APPENDIX 1

GEO REQUIREMENTS
TECHNICAL ISSUES

6.1 UNIQUE HUMAN CAPABILITIES IN GEO

Introduction: Over the past several years a number of studies have been performed that address the capabilities and limitations of human operators in the space environment. Most are thorough, in-depth analyses and provide a comprehensive knowledge or reference base for application to specific mission requirements. Two references in particular illustrate the breadth of these efforts. THURIS (The Human Role in Space) is an exhaustive treatment of the human operator's potential. ARAMIS (Automation, Robotics and Machine Intelligence Systems) represents studies that have investigated the various levels of augmentation (of the human operator) that have application to space operations. In summary, there are already sufficient data available to support general planning for the use (or augmentation) of the human operator. The purpose in the discussion below is to focus on the unique human capabilities and unique operational contexts relevant to GEO operations.

Justification: The identification of unique human capabilities and applications to GEO mission activities is required for intelligent and timely GEO mission planning.

Proposed Outline of Technology Area:

Comment: The topical summary below is intended as a topical outline of unique human capabilities that have a special application to GEO, or unique GEO considerations that present a potentially productive application for crewmembers at GEO, i.e., there is no claim that a human's unique capabilities are any different at GEO than those existing at LEO.

I. RELEVANT CONSIDERATIONS FOR GEO MANNED OPERATIONS

1. Environment
   1.1 Physical objects in GEO and GEO-transiting trajectories
      1.1.1 GEO satellites
         1.1.1.1 Functional satellites
         1.1.1.2 Derelict satellites
         1.1.1.3 Debris
         1.1.1.4 Meteoroids
2. Remote location (distance from Earth)
   2.1 Threshold limits of Earth-based sensors and instruments
   2.2 Threshold limits of space-based sensors and instruments
   2.3 Attenuation
      2.3.1 Visible light (distance + atmosphere)
      2.3.2 Radio frequency signals
      2.3.3 Amplified signals (laser and maser)
      2.3.4 Gravity
      2.3.5 Magnetic field strength

II. POTENTIAL SITUATIONS REQUIRING THE APPLICATION OF UNIQUE HUMAN CAPABILITIES

Discussion

The following are postulated situations and conditions under which a human operator could be required to intervene. In fact, there are experience precedents from past space missions that support each item covered. Except for missions designed to utilize EVA operations as a nominal flight activity, the traditional course of action has been to use EVA after all else fails. The situations outlined below are intended to show that nominal operations may require human presence in addition to the remedial role

often cited. As an example, there may be an overriding need to certify the validity of Earth tracking and size determination of GEO debris objects and distribution (flux). This may be possible only by using a crew at GEO to do a short term mission in coordination with ground tracking facilities to check validity. The time factor may not permit the development of automated equipment even though suitable instruments exist to perform the task. Further, with crewmembers present, the opportunity will exist to operate equipment in modes unanticipated during mission planning or in configurations and combinations not envisioned. Another human aspect of presence is the ability to operate with degraded equipment and to bring to bear an element of human motivation that cannot be designed into equipment. In the past, EVA has been crucial on frequent occasions when such difficulties and opportunities have been encountered. It would be unwise not to anticipate EVA operations serving such roles in future GEO missions.

1. Earth-based activities (limitations)
   - 1.1 Inability to detect, track or map GEO objects TBD size (detection and tracking sensitivity)
   - 1.2 Inability to determine size of GEO objects (discrimination)
2. Space operations
   - 2.1 Automated space hardware and software limitations
     - 2.1.1 Limited flexibility to vary operating protocols
     - 2.2.2 Limited flexibility to alter hardware and software configuration
     - 2.2.3 Limited flexibility to perform iterative improvements to exploit real-time discoveries (in situ "bootstrapping")
     - 2.2.4 Limited flexibility to alter or correct physical configuration anomalies or inadequacies
       - 2.2.4.1 Jammed, stuck or inoperative mechanisms

2.2.4.2 Debris and contaminants degrading instrument performance (e.g., fibers on lens)

2.2.4.3 Inadequate design consideration

2.2.4.3.1 Mechanism travel range

2.2.4.3.2 Mechanism protective stops

2.2.4.3.3 Protective guards, rails or surfaces (self damage)

2.2.4.3.4 Protective shields and barriers (thermal, electromagnetic, ionizing radiation, amplified [laser, maser])

6.2 EVA CREWMEMBER IDENTIFICATION AND TRACKING SYSTEM

Introduction: The presence or absence of a color band on the EVA crewmember's suit has been used to the present time for easy identification of the individual. Under most circumstances this system is entirely adequate. Although the GEO missions currently envisioned will involve no more than two EVA crewmembers, Space Station EVA operations and eventually GEO EVA operations will require more than two people and the individual identification of crewmembers may become more difficult. Consideration should be given to developing a more positive system that will assure ready and positive identification or recognition of an EVA crewmember under observation. With the increasing number of EVA crewmembers deployed, the task of keeping track of all the people will likely exceed the capabilities of a single IVA monitor. Under such circumstances a need will arise to provide full sphere tracking or monitoring of the EVA workforce deployed. A combination of visual, optical and electronic techniques might be required.

Justification: An EVA crewmember identification and tracking system is needed to improve operational efficiency and enhance crew safety.

<u>Proposed Outline of Technology</u>:

I. EVA CREWMEMBER IDENTIFICATION AND TRACKING OPTIONS

1. Direct visual
   - 1.1 Color
   - 1.2 Graphic
   - 1.3 Numerals
   - 1.4 Active lighting (day or dark)
     - 1.4.1 Color
     - 1.4.2 Flash pattern, sequence

1.4.3 Beacon (steady, response)
1.4.4 Low power laser and laser reflector

2. Electronic and radio frequency
   2.1 Continuous (radio frequency beacon)
   2.2 Transponder
   2.3 Passive (radio frequency corner reflector)
3. Tracking options
   3.1 Direct observations
   3.2 Automated detection and tracking
4. Automated capabilities (full sphere monitoring)
   4.1 Location specification (direction cosines, clock system [e.g., 2:00 high], other)
   4.2 Status and position monitoring capabilities
      4.2.1 Position
      4.2.2 Range
         4.2.2.1 Safe-range thresholds (limit monitor)
         4.2.2.2 Range rate thresholds (limit monitor)
      4.2.3 Attitude limit thresholds (loss of control - EVA enclosure)
         4.2.3.1 Below rate limits (inactive > TBD minutes)
         4.2.3.2 Excessive rate (uncontrolled tumble)
   4.3 Visual, optical, video coupling and pointing
      4.3.1 Viewing angles guide to IVA
      4.3.2 Automated optical aid pointing
      4.3.3 Automated video camera pointing
5. EVA crewmember interrogation capability (locate another EVA)

6.3 FLIGHT PLANNING DOCUMENT - GEO

Introduction: Several questions have arisen during the ADVEVA study that indicate a need for an integrated reference that (a) provides GEO data of the type that are normally found in a flight planning reference, (b) comprises a consolidated reference of these data and (c) comprises an official document for standardization of these data and a central focus for review, update and correction, and additions.

Justification: Planners for GEO (and later Lunar and Mars) missions need an authoritative document for getting required data to do their work related to flight planning and they also need a central point to clarify or introduce issues that arise (better data, more data, new data).

<u>Proposed Outline of Technology Area</u>:

I. DATA SCOPE OF THE FLIGHT PLANNING DOCUMENT (GEO)

1. LEO-GEO environmental factors
   - 1.1 Electromagnetic radiation
   - 1.2 Lighting (special case for visible radiation)
   - 1.3 Thermal
   - 1.4 Debris and meteoroid hazard
   - 1.5 Microgravity levels
   - 1.6 Vacuum level(s)
   - 1.7 Atmosphere
   - 1.8 Electrostatic
   - 1.9 Earth wake (cometary tail)
2. GEO trajectory and flight path description, considerations (in support of EVA missions, but not strictly confined to EVA requirements)
   - 2.1 Types of geosynchronous trajectories
     - 2.1.1 Equatorial circular (stationary)

    2.1.2 Equatorial elliptic
    2.1.3 Inclined circular
    2.1.4 Inclined elliptic
  2.2 Transfer trajectories
    2.2.1 LEO-GEO, GEO-LEO
      2.2.1.1 Phasing at LEO (departure and return)
      2.2.1.2 LEO-GEO transfer and circularization
      2.2.1.3 Phasing at GEO (arrival and return)
      2.2.1.4 GEO-LEO transfer and circularization
  2.3 Rendezvous
    2.3.1 LEO
    2.3.2 GEO
3. Ephemeris, communication and tracking considerations
  3.1 Voice and data
  3.2 State vector
  3.3 GEO ephemeris factors and considerations
    3.3.1 GEO space and sector: control and sovereignty
      3.3.1.1 Claims, agreements and assignments
      3.3.1.2 GEO segment and sector definition
    3.3.2 GEO satellite classification
      3.3.2.1 Description and specifications [owner(s), size, weight and operating frequency(s)]
      3.3.2.2 Lifetime and disposition plan
  3.4 Unique GEO ephemeris data
    3.4.1 GEO eclipsing by Earth
      3.4.1.1 Clarke Belt (equatorial/circular)
      3.4.1.2 Other (see 2.1, above)
    3.4.2 Earth "cometary wake" transits
    3.4.3 Lunar cycle considerations
      3.4.3.1 Lunar perturbative cycles
      3.4.3.2 Libration points ephemeris
  3.5 Debris monitoring and management
    3.5.1 Debris ephemeris
    3.5.2 Debris removal schedule and responsibility
  3.6 Meteoroid ephemeris
    3.6.1 Steady state flux

3.6.2 Periodic flux (meteor showers)

II. SUGGESTED FEATURES DESIRABLE IN THE FLIGHT PLANNING DOCUMENT (FPD)

1. Orbital mechanics reference (in support of EVA missions, but not strictly confined to EVA requirements)
   - 1.1 Delta V requirements (see 2.2, above)
   - 1.2 Special case Delta V considerations
     - 1.2.1 Removal and disposal options
       - 1.2.1.1 Drop to LEO and reentry
       - 1.2.1.2 Inject to libration point
       - 1.2.1.3 Inject to solar
     - 1.2.2 High energy options and trades
       - 1.2.2.1 Quick drop to LEO
       - 1.2.2.2 "Sprint" transfer and injection options
         - 1.2.2.2.1 Lunar
         - 1.2.2.2.2 Planetary
   - 1.3 GEO orbit tuning and adjustment
   - 1.4 GEO orbit intrasector interleaving
   - 1.5 GEO rendezvous special considerations
   - 1.6 Standardized cartographic projection (for depicting GEO trajectories in an international system)
2. Tables, charts and graphs
3. Procedure and reference sources for assessing GEO temporal factors and issues
   - 3.1 Environmental dynamic conditions
     - 3.1.1 Ionizing radiation
     - 3.1.2 Debris and meteoroid hazard
   - 3.2 Legal issues and factors
     - 3.2.1 Existing and current
     - 3.2.2 Planned, projected agreements or arrangements

6.4 EXTENDIBLE/RETRACTABLE DEVICES TO ENHANCE EVA AND EXTERNAL OPERATIONS

Introduction: An Extendible/Retractable (E/R) device is envisioned as a device with an operating base (basemount) installed to a primary spacecraft in a compact housing, capable of being extended, retracted or possibly maneuvered (pointed, curved or rotated), with varying degrees of freedom (DOF) to (a) transfer crewmembers and equipment positioned on an endstation of the E/R or (b) effect docking or attachment to a satellite or other free hardware, using a grapple or capture fixture fitted to the endstation.

Justification: The following reasons are suggested as justification for an E/R device(s) for operations at GEO:

(a) Efficiency of operation: transferring equipment by E/R can (1) save EVA crewmember(s) time and enable optimum attention to EVA task at hand; (2) utilize the IVA crewmember as participant - substituting IVA time for EVA time; (3) provide a temporary work platform for EVAs while preparing a local workstation at the EVA worksite. In some cases the endstation may serve as a workstation (i.e., concept similar to the MFR/RMS combination). In comparison to the MFR/RMS, an E/R may have some advantages and some drawbacks, i.e., less accuracy, poorer close-in positioning capability, but greater distance, lower cost, less installation complexity, more adaptability to smaller spacecraft.

(b) Versatility: Adaptable to wide range of applications where a RMS could not be justified (or accommodated).

(c) Safety: Can relieve the EVA crew from handling hardware that involves a level of risk or where repeated transfers of equipment distract the EVA crewmember from a task in work that poses some risk to hardware, e.g., sensitive structure, equipment made vulnerable by inattention to parameter levels.

(d) Opportunity to apply emerging A/R technology to a device with productive operational payback.

Proposed Outline of Technology Area:

I. PURPOSE OF E/R EQUIPMENT

1. Transfer and position
   1.1 Crewmembers
      1.1.1 Nominal
      1.1.2 Contingency
   1.2 Equipment
      1.2.1 Nominal
      1.2.2 Contingency
2. Docking/Attachment
   2.1 Satellites
   2.2 Derelict hardware and debris

II. GENERIC E/R DESIGN CONSIDERATION

1. Load Package (LP) large mass handling capability
2. Load Package mass properties (capability to stabilize loads)
   2.1 LP center of mass (CM): CM offset
   2.2 LP moments of inertia
3. Load Package volume and dimensions
4. E/R packaging density (E/R package envelope/dimensions)
5. E/R package mass (weight penalty)
6. E/R energy requirements
   6.1 Deploy and stow
   6.2 Extend/Retract operations
7. E/R endstation services (capability to implement and accommodate)
   7.1 Power
   7.2 Data and TV
   7.3 Direct control of E/R

7.4 Lighting

8. Safety, reliability, maintainability and repairability
   - 8.1 Safety (crew or equipment entanglement, jettison capability)
   - 8.2 Maintainability and repairability (access and modularity)
   - 8.3 Manual backups and overrides
   - 8.4 Environmental vulnerability
9. Useful service life
10. Deplow and stow time
11. Operating and positioning envelope
    - 11.1 Basemount DOF
    - 11.2 Endstation DOF
    - 11.3 E/R extension range
12. E/R control station options
    - 12.1 IVA remote control
    - 12.2 EVA remote control
    - 12.3 EVA endstation direct control
13. E/R control features
    - 13.1 E/R position display (IVA): clarity and accuracy
    - 13.2 Range of control granularity (fineness and accuracy, high rate and save time)
    - 13.3 Position hold stability
14. IVA viewing capability (direct or imaging)

III. E/R DESIGN OPTION CANDIDATES

1. Ribbon booms
2. Scissors linkage booms
3. Telescoping booms
4. Jointed arm (RMS, "carpenter's rule," common robotic arm)
5. Stacked modules (e.g., Stewart Tables)
6. Inflatable booms and sleeves

IV. DISCUSSION OF SELECTION AND TRADEOFF CRITERIA

A full discussion of selection criteria is not feasible. Devices similar to some proposed above have been used in space but not always for the application suggested (E/Rs).

1. Skylab used a 10 meter (approximately) extendible ribbon boom (called the TEE) to transfer film magazines (approximately 30 kg) to and from the solar telescope film transfer workstations. The number of work cycles was limited (probably between 12-20 cycles) but the unit functioned without difficulty. The unit was limited to linear transfer to a single location and although it exhibited sufficient stiffness for the assigned task, it would not have supported a workstation or a crewmember.
2. Scissors linkage booms: The ATM solar panel wing on Skylab extended from a central package less than 0.5 m deep to a deployed length of 15 meters (approximately). Shuttle mission 41-D deployed an experimental solar array using a scissors mechanism.
3. Telescoping booms: Scientific Equipment Bay Boom, Apollo
4. Jointed arm: Shuttle RMS, extensive experience
5. Tiered modules [e.g., stacked Stewart Tables (intriguing concept supported by computer modeling only - Grant Number NAGW-847[NASA Headquarters Code E])]. This concept is described in a progress report, PERSONNEL OCCUPIED WOVEN ENVELOPE ROBOT, June 1, 1987, submitted to Code E. It appears to provide the effect of 6 DOF. The extension length limit can be varied by adding or reducing the number of Stewart Tables.
6. Inflatable booms and sleeves: Aside from the primitive Echo balloon satellite (early 1960's), and the inflatable airlock used by the Soviets for their first EVA, there is little operational data on the use of inflatables as structural members.

The following matrix is suggested as a rough evaluation of the six options mentioned above. The criteria are listed by number reference (paragraph II, above) across the top, opposite the six options (paragraph III, above) in the left column. The ratings are subjective (in some cases hypothetical) and are included merely as an example of a matrix rating.

GENERIC E/R DESIGN CONSIDERATIONS (Paragraph II, pages 176-177)
(Numerical Column Headings are Subparagraph Numbers of Paragraph II)

Option	1	2	3	4	5	6	7	8.1	8.2	8.3	8.4	9	10	11	12.1	12.2	12.3	13.1	13.2	13.3
1	2	2	?	3	L	L	0	3	1	3	3	2	3	1	3	3	0	3	3	1
2	3	3	?	2	M	M	3	2	2	2	3	3	2	1	3	3	3	3	2	3
3	2	1	?	3	L	L	1	3	1	1	3	2	3	1	3	3	1	3	3	2
4	3	3	?	1	H	M	3	2	2	2	3	3	2	3	3	3	3	3	2	3
5	3	3	?	2	H	H	3	2	2	1	3	3	2	3	3	3	3	3	2	3
6	1	0	?	3	L	L	0	3	1	0	1	1	3	1	3	3	0	2	3	0

Criteria Rating:

0 = unsuitable; probably unsuitable or unable to implement

1 = marginal or poor capability to implement

2 = fair or favorable capability to implement

3 = good or high probability to implement

L = low M = medium H = high ? = unknown or undetermined

6.5 INTERNATIONAL SYMBOL/SIGNALING SYSTEM (ISSS)

Introduction: The number of different nations now participating in space missions has increased to the point where there is need for agreement on the use of a standardized system of symbols and signals in placards, decals and non-linguistic audio/visual communication. Such a system could be used to identify hazardous, sensitive or fragile equipment; maintenance or servicing areas or zones; access ports, panels, hatches and doors to enable safe and effective operations on any satellite by owner or agent parties, and to enable communication in the absence of common language, radio frequency communication link and degraded spacecraft performance. There is ample precedent for such a space system as illustrated by the systems used in maritime and aeronautical activities and enterprises.

Justification: As the number of national participants in space missions increases, there will be a requirement for an International Symbol/Signaling System (ISSS) to assure safety and efficiency during space operations and to enable a wider variety of cooperative international space mission operations. The symbols, codes, and communication systems used by road traffic systems, maritime shipping and air traffic are examples of successful implementation of such an international system. The prime motive in all of the above existing systems is safety, but a valuable and productive by-product is increased efficiency of operations. With the increasing use of geosynchronous orbit by many nations, the need will arise to remove derelict satellites that threaten the GEO region. Such "salvage" operations may be beyond the resources and capabilities of the owners of such derelict satellites andthe major spacefaring nations will likely assume the responsibility (perhaps shared) to clean up the mess to guarantee the safety of their own satellites. Thus, there is a distinct probability that space crews will be

required to approach, assess, passivate, service and attach thrusting devices during the course of salvage and renovation tasks. Even if automated activities are preferred, remote operations would be enhanced if remote visual aids (TV) are employed.

Proposed Outline of Technology Area:

I. ONE-WAY ISSS

1. Visual
  1.1 Graphics
    1.1.1 Signs (e.g., road signs, buoy markers, radiation sources and high voltage)
    1.1.2 Graphic patterns (applied over an area) depicting full extent of hazard, sensitivity and vulnerability
  1.2 Position indicators
  1.3 Visible light
    1.3.1 Beacons
    1.3.2 Codes and patterns
2. Radio frequency devices
  2.1 Beacons
  2.2 Status messages
  2.3 Data and TM transmissions (automated periodic)

II. TWO-WAY ISSS

1. Crew-to-crew (non-voice)
  1.1 Visual
    1.1.1 Graphics
      1.1.1.1 Status signaling
      1.1.2.2 Simple message communication
    1.1.2 Light codes
      1.1.2.1 Status signaling
      1.1.2.2 Simple message communication

1.1.3 Radio frequency unmodulated (modified international Morse Code system)

1.1.3.1 Status signaling

1.1.3.2 Simple message communication

2. Crew-machine interactive

2.1 Indicator response

2.1.1 Digital and analog indicators

2.1.2 Lights

2.1.3 Physical status indicators

2.1.3.1 Position and travel

2.1.3.2 Open or closed, locked or unlocked, safe or unsafe

2.1.4 Data access ports and links

III. POSSIBLE APPLICATIONS

1. Satellites

1.1 Hazardous areas

1.1.1 Mechanical and structural

1.1.1.1 Crew hazard

1.1.1.1.1 Impact or contact with sharp edges, surfaces, points

1.1.1.1.2 Release of stored mechanical energy

1.1.1.2 Equipment hazard

1.1.1.2.1 Crew or equipment contact with fragile or vulnerable structure

1.1.1.2.2 Positioning of components outside design travel range

1.1.2 Chemical

1.1.2.1 Pyrotechnics or explosives

1.1.2.2 Toxic or caustic material

1.1.3 Thermal

1.1.3.1 Hot

1.1.3.2 Cold or cryogenic

1.1.4 Ionizing radiation (radioactive)

1.1.5 Non-ionizing radiation

1.1.5.1 Frequency-related (e.g., UV, intense IR, intense visible)
 1.1.5.1.1 UV
 1.1.5.1.2 IR
 1.1.5.1.3 Visible
 1.1.5.1.4 Radio frequency
1.1.5.2 Amplified non-ionizing (e.g., laser, maser)

2. Operational situations (crew-crew)
 2.1 Failed voice
 2.2 Low electrical power available
 2.3 No common language
 2.4 Trailblazing (leaving markers, tracks)

IV. ADDITIONAL CONSIDERATIONS

In addition to the categories and types of hazards, a feature of the ISSS should depict and inform regarding the level or intensity of hazards. For example, the code used to indicate the presence of ionizing radiation does not reveal the intensity or level of risk related to the source (nor, in many cases, its precise location). Thus the following should also be a consideration in developing the ISSS:

1. Intensity or level of the hazard
 1.1 Ionizing radiation
 1.2 Non-ionizing radiation
 1.3 Mechanical
 1.4 Chemical
 1.5 Thermal
2. Location (if not obvious)
 2.1 Hazard location
 2.2 Safing controls
 2.3 Releasing controls
 2.4 Capture, containment, shielding, hold down-restraint provisions or installation points and positions

6.6 RIGIDIZING ATTACHMENT BOOM (RAB)

Introduction: During the development of the scenario for the GEO EVA mission, an operational mode was identified that introduces new requirements. That operating mode is as follows: An EVA team is working on a large satellite (inactive control system) in close proximity to the manned spacecraft. In the case of the GEO scenario, the satellite dud was an OTV entangled with a GEO satellite it was sent to repair (automated mission). The problematic situation is analogous to an Orbiter attempting EVA repair work on a disabled satellite without benefit of an RMS. Although this situation could be handled by operating with the EEU, lengthy or complex repair tasks are better accomplished when there exists a rigid attachment between the spacecraft (Orbiter) and the satellite. The preferred operating mode has been to use the RMS to "berth" or position the satellite in the payload bay where the satellite was secured by EVA crewmembers prior to beginning work. This procedure assumes that the satellite poses no hazard to the Orbiter. In the case of GEO EVA rescue, repair and salvage missions, such a benign status regarding the satellite cannot be presumed. However, a need for a temporary "hard" connection between the spacecraft (MOTV in the case of the GEO scenario) and the satellite still exists. A rigidizing attachment boom (RAB) would provide this feature. The attachment/docking of the RAB to the satellite could be implemented by a general purpose grappler on the end of the boom or by EVA attachment of a temporary attachment/docking fixture to the satellite (see separate description: attachment/docking fixture).

Justification: The following reasons are proposed as justification for developing a RAB:

(a) Safety: Crew safety is improved by having a stabilized work location. Spacecraft safety is enhanced by holding the satellite at "arms length" at an assured separation distance and relative position and

(b) Task efficiency: The EVA work will be much more efficient when conducted on a stabilized work area. Transfer of the EVA crewmembers, equipment and tools between the spacecraft and the satellite will be easier and quicker.

The following considerations are considered relevant to specifying the design features of the RAB:

I. PURPOSE OF RIGIDIZED ATTACHMENT BOOM (RAB)

1. Stabilizing satellite (or other space hardware) relative to the spacecraft
2. Assuring separation distance between the spacecraft and the satellite
3. Providing a transfer path between the spacecraft and satellite for crewmembers and equipment
   3.1 RAB with integral handrails and handholds
   3.2 RAB with fittings for attaching handrails and handholds
   3.3 RAB with integral transfer device (cable or trolley)
   3.4 RAB with fittings for attaching transfer devices

II. DESIGN FEATURES

1. Physical
   1.1 Deployable/retractable
   1.2 Extended length
      1.2.1 Range: Up to 15 meters
      1.2.2 Rigidizing characteristics maintained throughout extended range
      1.2.3 Controllable EVA as well as IVA

1.2.4 Transfer capabilities (crew and equipment) preserved irrespective of extended length

1.3 Optimized packing density and mass

2. Operational

2.1 Crew safety

2.1.1 Low risk of crewmember entrapment

2.1.2 External emergency controls

2.1.3 Jettison capability

2.2 Operational efficiency

2.2.1 Effective control and display (IVA and EVA) provisions

2.2.1.1 Configuration and extended distance

2.2.1.2 Accuracy of indications

2.2.2 IVA visual capability (direct or imaging)

2.3 Deploy and retract time

2.3.1 Rapid setup and stow

2.3.2 Variable rates to suit operational need

2.4 Accommodation of worksite endstation services

2.4.1 EVA crewmember workstation and restraint

2.4.2 EVA equipment and tool restraints and platforms

2.4.3 Power, TV, data and lighting

2.4.4 RAB control station

III. INTEGRATION OF RAB WITH EXTENDER/RETRACTOR (E/R) DEVICE

The concept of the RAB is similar to the E/R in many respects. A comparison of the two reveals many similarities. However, the primary purposes are different. The RAB is intended to hold a satellite in a fixed relative position relative to the manned spacecraft. The E/R is primarily intended to expedite translation of crewmembers and equipment between the spacecraft and the EVA worksite. It would appear that the two concepts could be merged to satisfy both requirements with a single piece of equipment.

6.7 COMMUNICATIONS/VIDEO FEATURES

Introduction: A frequent and recurring problem on virtually all space missions (Apollo, Skylab and STS) has arisen from inadequate knowledge of communication/video configurations. Such situations have resulted in unintended transmissions of informal verbal exchanges (onboard) and in failure to record data during a variety of operational situations. The consequences range from simple embarrassment to loss of valuable data. The situation could be corrected by incorporating features in the design of control and indicators that provide the crewmembers with greater visibility over the communication, data and video setups.

Justification: Design features that provide the crew with precise, easily interpreted information on the communication, data and video equipment configuration would provide the following benefits:

(a) Greater assurance against loss of data,

(b) Greater confidence in preventing unintentional downlink of data (for reasons of security and personal privacy) and

(c) Operational flexibility and safety by assuring proper configuration during critical mission phases.

<u>Proposed Outline of Technology</u>:

I. CONFIGURATION AND STATUS INDICATORS

1. Configuration selected
   - 1.1 Voice
   - 1.2 Data
   - 1.3 Video
2. Modulation and signal generation
   - 2.1 Voice modulation occurring
   - 2.2 Data modulation occurring

2.3 Video modulation occurring (camera working)

3. Ground-flight signal (carrier) lockup achieved (voice, data, video)
4. Ground-flight carrier being modulated (voice, data, video)
5. Video recorder receiving
   5.1 Signal (carrier)
   5.2 Modulated signal
6. Location of displays and indicators
   6.1 Central data display(s): panels and CRTs.
   6.2 Device and selection panel location (communication panel, video camera and VCR)

Supplemental discussion: Another feature that deserves consideration is enabling onboard capability for EVA crewmembers to employ a temporary "lockout" feature to assure against (a) voice downlink and (b) voice interruption from ground. There are several situations during which such a lockout feature would be advantageous:

1. To guarantee against disclosures of data (security and proprietary),
2. To prevent interruptions during critical sequences and
3. To enable real-time crew open or frank discussions of pending tasks that they might otherwise be reluctant to discuss.

Such a feature should be used with great discretion and, when used, there should be a continuous and unmistakable audio indication that the lockout mode is in force.

6.8 SHADING DEVICE FOR WORK IN CONSTANT LIGHT - GEO

Introduction: Planning for EVA work at GEO will require consideration for the virtually constant lighting situation at the GEO altitude. The sun side of a satellite or space structure may require shading or partial shading for some types of operations and activities related to maintenance, servicing and repair. The use of a shade may be required to create the proper illumination or thermal conditions for the EVA crewmembers or the space hardware and equipment.

Justification: EVA Shading devices may be required to

(a) Permit operations in light-sensitive areas of satellites,

(b) Reduce adverse lighting conditions for the operator (reflections, glare, washout),

(c) Control thermal conditions in a work area and

(d) Enable selective exposure of light on active space hardware for diagnostic procedures (photovoltic and other types of solar power activated equipment, radiators).

For a modest investment in resources, a range of available shading devices could provide additional options in planning GEO EVA tasks and increase operational versatility and efficiency. The following is a summary of the advantages of providing shading capability:

(a) Low cost

(b) Safety (equipment and crewmember)

(c) Operational flexibility and versatility

Proposed Outline of Technology Area:

I. LIGHT (ILLUMINATION) CONSIDERATIONS

1. Enhanced EVA crewmember and operational efficiency

1.1 Reduce or eliminate reflections, glare, washout (surface texture evaluation, reading LEDs, instruments)
   1.1.1 Opaque shades
   1.1.2 Translucent shades
2. Protection of light-sensitive and thermal-sensitive areas exposed during EVA servicing, maintenance and repair activities
   2.1 Inability to protect work area by selective orientation of work area to shaded side (maneuvering of satellite is undesirable for operational reasons)
   2.2 Time or propellant constraints don't permit reorientation of satellite or work area

II. THERMAL CONSIDERATIONS

1. Reduce thermal load on EVA enclosure
2. Reduce thermal load on equipment and hardware

III. DIAGNOSTIC/TROUBLESHOOTING CONSIDERATIONS

1. Radiator surfaces
2. Solar panels (photovolatic)
3. Solar dynamic

IV. SHADE PROPERTIES SPECIFICATIONS

1. Size and shape (range of sizes available)
2. Compatibility with positioning equipment (RMS, EEU)
3. Shade deployment techniques mechanisms
   3.1 Parasol (circular)
   3.2 Multifold (scissors) screens (rectangular)
4. Opacity or translucence
5. Packaging and stowage
   5.1 Mass
   5.2 Packaging density or compactness

6. Operating factors

6.1 Deploy and retract time

6.2 Remote positioning options

6.2.1 IVA

6.2.2 EVA

6.9 ATTACHMENT/DOCKING FIXTURE

Introduction: In the future, a mission or EVA task will involve work with a satellite or piece of space hardware without provisions for grapple, dock or other accommodations for a mechanical linkup with "standardized" active devices, i.e., RMS, EEU, docking probes and interfaces. There is a need to develop a device that incorporates two features: First, a satellite and space hardware interfacing attachment (shroud, net, tongs, jaws, vise, and clamp) that effects a mechanical attachment with the free space hardware item and has a universal mating interface (like a grapple fixture). Second, that it accepts a variety of interface adapters that make the prepared space hardware attachment compatible with the active mission hardware [RMS, EEU, active docking structure (probe, collar)], e.g., enables a two-step prep of space hardware - attaching the mechanical interface to the hardware, then mating the adapter to the mechanical interface. The space hardware would then be prepared to accommodate the handling protocol for the mission hardware. Consideration should be given to enable the mechanical attachment to accept more than one adapter, thus enabling an EEU to handoff hardware to RMS, or RMS handoff to second RMS.

Justification: Shuttle experience has demonstrated the need for preparing space hardware to be handled by standard mission devices such as the RMS and EEU (trunnion pin attachment device [T-PAD] problem, other satellite repairs). The following appear to be ample justification for the hardware proposed:

(a) Enables mission operations using standardized hardware and procedures, i.e., makes a wide range of mission tasks feasible (operational flexibility and versatility),

(b) Saves mission and EVA time,

(c) Enables safer operations,

(d) Enables missions on a wide range of space hardware (satellites, debris) both US and international and

(e) Could serve as a focal point for standardizing A/R interfaces on an international basis.

Proposed Outline of Technology Area:

I. MECHANICAL ATTACHMENT

1. Size and volume accommodation range
2. Mass handling capability
3. Method of attachment
   - 3.1 Shroud, net and cage
   - 3.2 Clamping mechanisms
   - 3.3 Pin and rod truss
   - 3.4 Other
4. Ease of attachment
5. Mode of attachment
   - 5.1 Manual
   - 5.2 A/R implementation
6. Containment and inerting capability (effective imprisonment or passivation of space hardware item)

II. OTHER HARDWARE CONSIDERATIONS (ATTACHMENT AND ADAPTER)

1. Variety of attachment devices required to accommodate the range of hardware anticipated (volume, mass, dimensions, protrusions)
2. Packaging, deployment and stowage of attachment
3. Hardware prep tools
   - 3.1 Cutters and loppers (pruning shears)
   - 3.2 Safing covers and shrouds (crewmembers and spacecraft) for hazardous structure, electrical and electrostatic, chemical, pyrotechnic and stored mechanical energy.

3.3 Charge neutralization ("grounding" wires and wands) provisions and tools

3.4 Thruster package attachment (tractor and pusher options)

3.5 Other

III. RELATED ITEMS

1. International endorsement and agreements
2. International standards

   2.1 Hardware

   2.2 Labels, placards, codes, symbols and graphics

6.10 WORK AREA SAFING KIT (WASK)

Introduction: Experience during past EVAs has pointed out the need for devices to render an EVA work area safe for (a) crewmembers and (b) hardware and equipment. In the future, EVA may be conducted on satellites or space hardware whose configuration may be (a) not designed with EVA in mind as a feasible option or (b) unknown or known with uncertainty. Normal EVA planning usually guarantees that the EVA crewmembers are well-briefed regarding physical hazards pertaining to the worksite, and mission-specific equipment is fabricated for the task at hand . The same will probably be true for any ad hoc protective equipment required for sensitive structure and surfaces of the satellite and space hardware. However, future EVA (such as a GEO mission based from Space Station) may not allow the time or opportunity to prepare such equipment. There appears to be a need for a general purpose Work Area Safing Kit (WASK) that will support the requirement to render a work area safe for the crew.

Justification: Crew safety may be a paramount concern when staging contingency EVA missions. Fragile equipment in a proposed EVA work area (or any adjacent surface) may be a major concern. Priority, expediency, planning simplification, and mission safety will be well served if a WASK is available (on orbit) to implement work area safing. The following reasons summarize a justification for a WASK:

(a) Crew and equipment protection (safety),

(b) Planning simplification: reduces complex procedural workarounds,

(c) Saves time during EVA if elaborate precautionary procedures are required,

(d) Reduces likelihood of human error (in the case of c., above) and

(e) Avoids further costly repairs to equipment.

Proposed Outline of Technology Area:

I. SAFETY

1. Crew protection
   1.1 Structural hazards (sharp edges, surfaces, points and abrasions)
   1.2 Electrical or electrostatic shock or discharge
   1.3 Chemical contamination
   1.4 Stored mechanical energy
   1.5 Explosives or pyrotechnics
   1.6 Other
2. Equipment protection
   2.1 Structural and mechanical damage
      2.1.1 Cantilevered structures: inadvertent damage caused by brushing against, grabbing by EVA crewmember (e.g., antennas, feedhorns)
      2.1.2 Sensitive or fragile surfaces (photovolatic surfaces, antenna mesh, optics)
   2.2 Chemical
      2.2.1 Effluents from base spacecraft, EVA enclosure, EEU, test and repair equipment
      2.2.2 Inadvertent releases from satellite being tended
   2.3 Electromagnetic
      2.3.1 Electrical or electrostatic
         2.3.1.1 Radio frequency energy from spacecraft, EVA equipment
         2.3.1.2 Electrostatic discharges arising from approach by spacecraft or EVA crewmember or EVA equipment
         2.3.1.3 Test or check-out equipment voltage
      2.3.2 Other (ionizing or non-ionizing radiation)
         2.3.2.1 Visible light exposure (sensitive optics)
         2.3.2.2 Removal of ionizing radiation shields
3. WASK specifications and description
   3.1 Structural covers

3.1.1 Rigid shrouds and enclosures

3.1.1.1 Dense packing (compact packaging)

3.1.1.2 Readily deployable and closeable

3.1.1.3 Readily attachable or removeable

3.1.2 Flexible surfaces

3.1.2.1 through 3.1.2.3 as per 3.1.1.1 - 3.1.1.3, above

3.2 Chemical barriers

3.3 Electromagnetic devices

3.3.1 Charge neutralization devices

3.3.2 Radio frequency management shields and procedural protocols

3.3.3 Light shields

3.3.4 Ionizing radiation shields

3.4 Miscellaneous features

3.4.1 Generic attachment devices

3.4.2 Orientation joint mechanisms

6.11 GENERIC FABRICATION KIT (GFK)

Introduction: The human capacity to invent new uses for equipment and materials at hand has been well recorded. On Skylab, the crewmembers fabricated a variety of devices to serve needs as they arose. The devices varied in sophistication from rewiring and assembly of ad hoc experimental equipment to modifying vacuum cleaner attachments. Shuttle mission 51-D is another good example of the continuing reliance on onboard fabrication in attempting to solve unanticipated problems. There is every reason to believe that future missions will also be faced with the need to fabricate devices onboard and, in fact, the need will likely increase dramatically with the advent of Space Station. Providing a small store of potentially useful items and materials for contingency or off-nominal repair and "work-around" would enable the EVA crew to develop effective solutions to unforeseen problems or circumstances without cannibalizing other available systems.

Justification: There is ample reason to believe that there will be a recurring need for a Generic Fabrication Kit (GFK) aboard future space missions. The following points are offered as justification for creating a GFK:

(a) Demonstrated need by historical precedent,

(b) Increasing space mission participation (more people, more missions, more equipment = more problem situations),

(c) Increasing complexity of operations, both in complexity and sophistication of the equipment and the total variety and scope of the equipment and facilities,

(d) Requirement to extend lifetime of space hardware (e.g., Space Station 30-year life),

(e) Prevent scavenging or cannibalization of onboard equipment (CRT changeout on 41-D - wouldn't have been helped by GFK but illustrates the tendency),

(f) Use of carefully selected materials with prescribed applications can prevent damage to equipment by the inappropriate or hasty use of incompatible or otherwise improper materials or tools for the application at hand and

(g) Flight safety - a well-designed GFK can improve crew survivability by providing an onboard capability to react to novel contingency or emergency situations.

Based upon a cursory evaluation of past crew resourcefulness in situations requiring onboard fabrication, the question is not IF there will be onboard fabrication but HOW can it be best facilitated. It can be done inefficiently using whatever materials or tools are available, or it can be done more effectively using a GFK selected with proper regard to (a) the space hardware and environment operational situation and (b) crew training to provide the necessary basic knowledge and skills.

<u>Proposed Outline of Technology Area</u>:

I. GFK (GENERIC FABRICATION KIT) COMPOSITION CONSIDERATIONS

1. Operational context
   - 1.1 Mission complexity (operations)
   - 1.2 Spacecraft complexity (hardware and equipment)
   - 1.3 Mission risks and hazards
     - 1.3.1 Extent of reliance on onboard repair
       - 1.3.1.1 Mission length
       - 1.3.1.2 Access time from next "higher order" facility (ground or Space Station)
     - 1.3.2 Mission priority and importance
   - 1.4 Application environment

1.4.1 IVA

1.4.2 EVA

1.5 Spacecraft support and facilities

1.5.1 Complementary tools

1.5.2 Workspace and workbench

1.6 Stowage, packaging, portability and inventory depth

II. CREW INTERFACE CONSIDERATIONS

1. Crew training
2. Flight experience records, evaluation and critique
3. Crew specialization

III. GFK PLANNING FACTORS

1. Candidate equipment and hardware

1.1 Spacecraft systems and equipment

1.2 Specialized mission equipment

1.2.1 Operational

1.2.2 Experimental and scientific

2. Timelines
3. GFK job execution waste products

3.1 Containment and packaging

3.2 Stowage and disposition

4. General application categories (projected areas of use)

4.1 Spacecraft structure

4.1.1 Primary structure

4.1.1.1 Pressure shell

4.1.1.1.1 Puncture path

4.1.1.1.2 Guards, shields and barriers

4.1.1.2 Truss and stiffeners

4.1.1.3 Bridges

4.1.1.4 Attachments

4.1.1.5 Hatches and windows

4.1.1.5.1 Hatches seal protection

4.1.1.5.2 Window shields and guards

4.1.2 Secondary structure and racks

4.1.2.1 Stiffeners, bridges and braces

4.1.2.2 Shields and guards

4.1.3 Spacecraft systems

4.1.3.1 Thermal isolation

4.1.3.2 Access and reach, aids and extensions

4.1.3.3 Tool modification

4.1.3.4 Airflow redirection

4.1.3.5 Wearpoint or abrasion, padding and protection

4.1.3.6 Jumper wire and cabling

4.1.3.7 Light shields and reflectors

4.1.3.8 Temporary containment barriers and enclosures

4.2 Mission equipment and instruments

4.2.1 Unanticipated protection provisions

4.2.2 Contact wear, impact damage or injury (guards, pads, barriers)

4.2.3 High voltage

4.2.4 Chemical or caustic

4.2.5 Biological

4.2.6 Thermal

4.2.7 Power supplement

4.2.8 Supplemental thermal (heating and cooling)

4.3 Special EVA

4.3.1 Tools

4.3.1.1 Tool modification

4.3.1.2 Tool fabrication

4.3.2 Ad hoc protective devices

4.3.2.1 See 4.2.1, above, as appropriate

4.3.2.2 Light management (reflectors, shades, baffles and non-reflective surface attachments)

4.3.2.2.1 IVA requirement

4.3.2.2.2 EVA requirement

4.3.3 Superficial structural modification

4.3.3.1 EVA work area enhancement

4.3.3.2 Operations contingency (supports and guard rails)

4.3.3.3 Radio frequency shielding

4.3.3.4 Service area(s) modifications

4.3.3.4.1 Crew and equipment protection

4.3.3.4.2 Crew aids (tool and equipment holders and retention modifications)

4.3.3.4.3 Safety enhancement modifications (guards, pads, spill barriers, and absorbers and contamination detector relocation)

6.12 EVA TRAINING FOR GEO MISSIONS

Introduction: Future EVA missions may originate from orbiting space platforms without the crew having the benefit of training for the mission in the traditional fashion (using ground facilities, teams, services). Onboard EVA support facilities should accommodate a wide variety of data and hardware needs, an EVA work planning and training area and a dedicated EVA storage and stowage volume. Possible EVA requirements that may impose requirements on generic space platform (Space Station) systems should be identified for advanced planning to avoid scheduling conflicts (e.g., tool kits, workbench, uplink and hard copy, work areas and volumes).

Justification: Mission safety and success will depend heavily on the effectiveness of the capability to conduct onboard EVA mission training. In some cases, the feasibility of an EVA mission may be determined by the onboard training capability. A well-planned EVA Inflight Training Package (EITP) could broaden the scope of feasible EVA missions as well as enhance the safety and effectiveness of such missions and efforts.

<u>Proposed Outline of Technology Area</u>:

I. GENERAL EVA INFLIGHT TRAINING PACKAGE (EITP) CONSIDERATIONS

1. EITP volume, area and zone
  1.1 Stowage and storage
    1.1.1 Dedicated
    1.1.2 Temporary or short term
  1.2 Equipment preparation
    1.2.1 Assembling of inventories
    1.2.2 Fabrication

1.2.3 Work materials kit preparation (caddy, carrier)

1.3 Task practice area(s) or zone(s)

1.3.1 IVA

1.3.2 EVA

1.4 EVA mission planning center (see 2.2, above)

2. EVA mission planning

2.1 Data support

2.1.1 Data base

2.1.1.1 Onboard

2.1.1.2 Ground: uplink to data base

2.1.1.3 Ground: uplink to hard copy printers

2.2 Control station availability (MPAC, special purpose)

2.2.1 Dedicated

2.2.2 Shared (specific station made available on as needed basis)

2.2.3 Temporary (any station made available on as needed basis)

2.3 Mission planning support

2.3.1 Activity and task scheduling and timelining

2.3.2 Mission equipment requirements

2.3.2.1 Hardware

2.3.2.2 Consumables

2.3.3 Mission task analyses

2.3.3.1 Task sequencing

2.3.3.2 Tool and specific equipment requirements

2.3.3.3 Crewmember coordination requirements

2.3.3.3.1 IVA and EVA

2.3.3.3.2 EVA and EVA

2.3.3.4 Crewmember skills requirements

2.3.3.4.1 IVA

2.3.3.4.2 EVA(s)

2.3.4 Identification of task focal points for EVA training

2.3.4.1 Critical to success of EVA mission

2.3.4.2 Time-critical

2.3.4.3 Skill development required

2.3.4.4 Automated or augmented assist device operation and manual backup tasks required

2.3.5 Procedure and checklist development

2.3.5.1 Onboard task analysis and assessment activities

2.3.5.1.1 Automated development

2.3.5.1.2 Manual development

2.3.5.1.3 Manual verification (runthrough trials)

2.3.5.1.4 Procedure media preparation

2.3.5.1.4.1 Hard copy (checklists, graphic aids)

2.3.5.1.4.2 Electronic [audio/video aids, voice-activated programs, logic and analysis guides (diagnostic/ troubleshooting)]

2.3.5.2 General mission planning

2.3.5.2.1 Nominal procedures and timelines

2.3.5.2.2 Backup, contingency procedures and timelines

2.3.5.2.3 Emergency procedures and timelines

2.4 Ground team participation levels and requirements

2.4.1 Primary responsibility

2.4.2 Support capacity

2.4.3 Ground-flight and flight-ground data and voice opportunities

3. EVA onboard training

3.1 Knowledge requirements

3.1.1 Mission hardware

3.1.2 Mission procedures, schedules and options

3.2 Skills requirements

3.2.1 Simulator and trainer capabilities

3.2.1.1 Mental and analytical skills development

3.2.1.2 Physical, dexterous and coordination skills development

3.2.2 Task environment requirements

3.2.2.1 IVA onboard training

3.2.2.2 EVA onboard training

4. Special equipment considerations
  4.1 Special purpose tools
  4.2 Custom fabricated devices (made onboard)
  4.3 Automation and robotics
    4.3.1 Data support (2.3.5, above)
    4.3.2 Physical support (EEU, RMS, MSC)

6.13 STANDARDIZATION OF FASTENERS

Introduction: One of the most time consuming activities during EVA is the removal and replacement of fasteners. Bolts and screws are the worst, because they require (a) repeated turns and (b) usually require a push force to maintain tool engagement with the head or slot. In addition, the screws are susceptible to slot damage and, in time, they may become very difficult to remove. Other problems arising during operations with threaded fasteners are: number of different size bolt heads (requiring socket or driver changeout), different size, type of slot recess (common, Phillips, Torx or Allen). A standardization policy regarding the selection of threaded fasteners could reduce the EVA task time and level of difficulty and, in addition, could preclude abandoning a planned EVA task because of damaged or inoperable fasteners. Ideally, the standardization policy should encompass design of space hardware on an international basis, to increase the feasibility or workability of EVA tasks on space hardware irrespective of the source builder.

Justification: Standardization of fastener design and use/application could provide the following benefits:

(a) Enhance crew and equipment safety,
(b) Save EVA crewmember time,
(c) Simplify task planning and timelining,
(d) Expand the scope of feasible EVA operations and
(e) Expand the scope of feasible robotic and teleoperated tasks.

Safety, crew time and task planning are optimized anytime the task is simplified. The scope of feasible EVA tasks is improved by eliminating single point roadblocks (damaged or broken fasteners) that render the task unworkable, either with crewmembers or robotic and teleoperated equipment.

Proposed Outline of Technology Area:

I. BASIC DESIGN CONSIDERATIONS (FASTENER)

1. Measurement systems
   - 1.1 English
   - 1.2 Metric
2. Head design and type and fastener and tool interface types
   - 2.1 Bolt
     - 2.1.1 Hex
     - 2.1.2 Square
     - 2.1.3 Levered
       - 2.1.3.1 Wing
       - 2.1.3.2 T-handle
       - 2.1.3.3 L-handle
       - 2.1.3.4 Other
     - 2.1.4 Star
     - 2.1.5 Round
       - 2.1.5.1 Smooth
       - 2.1.5.2 Knurled or ribbed
     - 2.1.6 Hybrid
       - 2.1.6.1 Knurled round or Allen recess
       - 2.1.6.2 Winged or slot recess
       - 2.1.6.3 Other
   - 2.2 Screw
     - 2.2.1 Slot (common)
     - 2.2.2 Phillips
     - 2.2.3 Allen
     - 2.2.4 High torque (torx)
   - 2.3 Bolt and screw head geometry
     - 2.3.1 Bolt head height
     - 2.3.2 Bolt head top surface
       - 2.3.2.1 Squared
       - 2.3.2.2 Rounded
     - 2.3.3 Screw head height

2.3.3.1 Raised head

2.3.3.1.1 Round or oval head (slot, Phillips, high torque)

2.3.3.1.2 Circular or squared-off top (Allen, high-torque)

2.3.3.2 Flush or countersunk

2.3.3.2.1 Slot (common)

2.3.3.2.2 Phillips

2.3.3.2.3 Allen

2.3.3.2.4 High torque or other

3. Threading

3.1 Convention or type

3.1.1 Measurement system

3.1.1.1 English

3.1.1.2 Metric

3.1.2 Machining convention

3.1.2.1 Machine thread

3.1.2.2 Electrical

3.1.2.3 Other

3.1.2.5 Self-threading

3.2 Threaded distance

3.2.1 Full length

3.2.2 Partial length

4. Length keying [use of unique length bolts and screws to indicate correct orientation of a rounded (square, hex) hardware interface]

5. Turns required to engage and release

II. CANDIDATE SELECTION CRITERIA TO SIMPLIFY FASTENER OPERATIONS

1. Employ single measurement system (English or Metric)

2. Apply coding to fastener head and hardware to indicate:

2.1 Size

2.2 Tool(s) acceptable

2.3 Length of fastener

2.4 Number of turns to release and install

2.5 Shear torque limit

2.6 Captive or non-captive

3. Minimize range of head designs

3.1 Minimize number of different types (e.g., hex)

3.2 Minimize number of different size heads

4. Specify free space envelope adjacent to head (recess enclosure and adjacent structure)

4.1 Enable tool engagement

4.2 Enable tool operation (rotation, lever throw)

4.3 Crewmember reach or access (MSIS)

5. Employ single threading convention

6. Fastener retention

6.1 Captive fasteners

6.2 Non-captive fasteners adaptive or compatible to captive attachment

6.2.1 Useable before fastener release

6.2.2 Coding to caution or inform when to attach or remove captive attachment

6.2.3 Clearly coded to indicate fastener is non-captive

6.3 Generic fastener retention or temporary stowage holder

7. Eliminate likelihood of cross-threading during replacement

8. Eliminate non-captive nuts

9. Eliminate "length keying" (see 1.4, above)

10. Eliminate countersunk heads

11. Eliminate screws (i.e., bolts only) other than Allen

12. Develop a class of fasteners to reflect EVA capabilities

7.0 APPENDIX 2

RECOMMENDED FURTHER STUDIES TO SUPPORT EVA AT GEO

7.0 RECOMMENDED FURTHER STUDIES TO SUPPORT EVA AT GEO

During the course of this phase of the contract there were several areas identified for which further studies and evaluations are appropriate. In some of these areas, data obtained were several years old, in others we have a non-existent or scant data base, and in still others there is developing information in areas outside of space systems which should be part of the EVA requirements data base. In order to satisfy the gaps in technology and pursue future studies, the following list will have to have priorities assigned to it in concert with other ongoing advanced study programs.

- Calcium Metabolism - The issue of long term exposure to higher than normal CO_2 levels and the subsequent effects on calcium metabolism needs to be more fully understood. There is some evidence from Earth-based studies that CO_2 will interfere with calcium metabolism. If this is the case, there may be important implications when calcium loss in the skeletal system as a result of microgravity is considered.

- Hand and Arm - The evolution of EVA glove designs has increased hand dexterity in EVA applications. While the design of future gloves will surely continue to improve dexterity and reduce fatigue, the effects are diminished with increased suit operational pressures. The study group was not able to identify a task-oriented physical training program to aid in conditioning hand and forearm muscles used in EVA tasks. A formal investigation is needed into what type of conditioning over what period might aid in reducing the muscular exhaustion experienced by EVA crewmembers.

- o Contamination Detection - The use of impregnated patches to indicate the presence of probable contaminants should be explored. Externally affixed patches that change color in the presence of contamination could be used on EVA enclosures, subsystems, and tools and would provide a coded colorimetric determination of contamination for self or "buddy" inspection.

- o Electromagnetic Radiation Shielding - The recent advances in high-temperature superconduction materials should be explored for possible application in setting up a magnetic shield around the MOTV. Dr. Jan BijVott, Executive Officer of the Consortium for Superconduction at the University of Alabama in Huntsville, (205) 895-6620, affirms that the use of superconducting magnets could induce a strong magnetic field around a spacecraft and attenuate direct radiation from solar events depending on the type and frequency of the radiation.

- o Solar Event Detection and Warning - The current detection methods for solar events rely principally upon direct measurements of the events. This affords insufficient time to descend to LEO and the Earth's protective magnetic shield. On the other hand, predictive models of potential solar events have a high component of false positives as well as a component of false negatives. In the first case, the GEO mission would be unnecessarily aborted and in the second, the event would be detected by direct measures, leaving only the normal two hours' warning before the highest radiation flux.

- o EVA Crewmember Location - Portable transponders which pinpoint the location and range of individual EVA crewmembers should be investigated for use in

maintaining active contact with the EVA crew, even in the event of incapacity. The devices should provide for identification of each crewmember as well as position and range with respect to the MOTV.

o Electromagnetic Field Detector - A very broad band RF detector for identification and display of real-time electromagnetic field intensity should be considered for EVA crewmembers working at GEO. This would provide warning of EM energy fields which may interfere with EVA operations, or pose a threat to EVA crewmembers.

o "Hands-in-Suit" Technology - While the MISTC is put forth as a strawman concept, a serious investigation of the feasibility of having "hands-in" capability for an EVA enclosure should be undertaken. The following areas of evaluation should be considered:

- Conducting waste management
- Eating and drinking
- Internal control layout
- Internal display layout
- Resizing for individual differences
- Reconfiguration for varying task requirements
- Self-administered medical care
- Provisions for emergency breathing masks and regulators

o EVA Crewmember Interfaces with Tools - While glove and tool interfaces and technology are being explored based on prior EVA experience, there are "through-the-wall" technologies being used in undersea applications that could increase human productivity in space. The techniques involve having at least one sleeve of the EVA enclosure terminating with a tool-holding fixture at the end of the arm. Now used in 1 ATM undersea hard suits such as JIM, the tools are controlled from inside

the suit by the bare-handed operator using a control stick. The commands from the internal controls are routed "through-the-wall" to the tool end effector which can provide rotation, grasping, and other manipulating functions based on the tool characteristics. This transfer of technology might lead to a reduction of hand and arm fatigue experienced by crewmembers using the approach of direct manual manipulation in the gloved hand.